LLŶR

LLŶR FLOATING OFFSHORE WIND PROJECT

Llŷr Floating Offshore Wind Farm

Environmental Statement

Appendix 22A: Annex B - Technical Papers on Survey Data Analysis

August 2024

Prepared by: Llŷr Floating Wind Ltd

FLOVENTIS ENERGY

Contents

As requested during pre-application consultation (**Chapter 22, Table 22-5**), HiDef has produced a series of technical papers on survey design and data analysis which are collated in this Annex:

This paper sets out the reasons for selecting a model-based method for survey data analysis, and why *Inlabru* was chosen in this regard. It also provides an explanation of the *Inlabru* modelling method. The paper was requested by NRW (A) at the first marine ornithology (and mammals) pre-application meeting held on 8 February 2023, with the paper issued to them on 16 March 2023, forwarded to JNCC on 18 May 2023 and then discussed together at the meeting held on 24 May 2023 (including a presentation on *Inlabru* provided by HiDef and DMP Stats).

This paper presents model (*Inlabru*) and design-based estimates for the seven seabird species addressed in quantitative assessment. It was requested by NRW (A) and JNCC at the meeting of 24 May 2023 (discussing *Inlabru*) and issued to them on 14 June 2023. (Note that some of these comparison estimates relate to the original Llŷr 1 proposed Array Area which has since been revised.)

This paper (also issued on 14 June 2023) was part of NRW (A) and JNCC's request made at the meeting of 24 May 2023. It includes model (Inlabru) and design-based estimates for harbour porpoise (Phocoena phocoena) and common dolphin (Delphinus delphis). (The key estimates are for the full survey area; as above, the ones produced for the Array Area + 4km buffer relate to the original Llŷr 1 proposal which has since been revised.)

This paper (issued 18 March 2024) was requested by NRW (A) and JNCC at the meeting held on 16 August 2023 and provides a comparison of density estimates (with associated precision) derived from digital aerial survey data at 12.5% (two cameras) and 25% (four cameras) survey coverage.

This paper (issued 18 March 2024) was requested at the Teams call of 16 November 2023 and deals with the treatment of uncertainty in marine ornithological impact modelling (collision risk and displacement) addressing matters raised by NRW (A) and JNCC during pre-application discussion and set out in detail in their advice note of 8 December 2023.

LLŶR FLOATING OFFSHORE WIND PROJECT

LLŶR SURVEY DATA ANALYSIS

Design and model-based analysis methods
HiDef advice to NRW

Prepared by: HiDef Aerial Surveying Ltd

March 2023

Acronyms and Abbreviations

Acronym or Abbreviation	Definition	Acronym or Abbreviation	Definition
CV	Coefficient of Variation	NRW	National Resources Wales
DAS	Digital Aerial Survey	NRW (A)	National Resources Wales (Advisory)
GRF	Gaussian Random Fields	OWEER	Offshore Wind Environmental Evidence Register
INLA	Integrated Nested Laplace Approximation	PAM	Passive Acoustic Monitoring
JNCC	Joint Nature Conservation Committee	SNCBs	Statutory Nature Conservation Bodies
LGCPs	Log Gaussian Cox Processes	SPA	Special Protection Area
MCMC	Markov Chain Monte Carlo	SPDE	Stochastic Partial Differential Equation

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1. Introduction

HiDef provided a survey summary paper (dated 20 January 2023) for discussion with Natural Resources Wales (NRW) Advisory (A) at a meeting held on 8 February 2023. Further to the matters raised at this meeting, NRW (A) provided their written advice in a paper dated 17 February 2023. This advice is welcome and closes out most of the issues that were under discussion at the meeting on 8 February 2023 (Sections 2-6 of NRW (A)'s paper). The key outstanding matters relate to survey methodology and design (as set out in Section 1 of NRW (A)'s paper).

So, this paper from HiDef sets out our advice on these issues considering NRW (A)'s suggestions for design-based estimation of species density and abundance (particularly in relation to seabirds) as well as setting out the detail of the inlabru (Bachl F. E., Lindgren, Borchers, & Illian, 2019) modelling method – HiDef's recommended approach to Llŷr digital aerial survey data analysis.

In the past year there has been separate publication of guidance from three out of the four UK Statutory Nature Conservation Bodies (SNCBs) on baseline characterisation of marine ornithology (and, in one instance, marine mammal) receptors at proposed offshore wind farm sites:

- NRW (2022). *At sea ornithological survey guidance*.
- Natural England – Parker *et al.* (2022). Phase III: *Expectations for data analysis and presentation at examination for offshore wind applications*.
- NatureScot (2023). *Advice for Marine Ornithology Baseline Characterisation Surveys and Reporting*.

As discussed with NRW (A) at the survey summary meeting on 8 February 2023 and in a short follow up call (27 February 2023), HiDef are keen for co-ordinated liaison (possibly via a workshop) in order to explore the logistical practicalities and feasibility of achieving any updated recommendations from SNCBs on digital aerial survey (DAS) work; design, analysis and reporting. As the current industry standard for DAS has been developed over time (>10 years), any recommended updates in approach cannot necessarily be achieved overnight, and there may be technical, logistical and cost limitations that apply to implementation.

We note the recommendation that individual project survey methodologies/plans are discussed with SNCBs in advance of surveys commencing and we will ensure (where possible)* that this takes place for all projects on which HiDef are undertaking the DAS.

* *This caveat is made as HiDef are not always the consultancy involved for project assessment or who are necessarily involved in project engagement with SNCBs over baseline characterisation.*

2. Design-based methods

As advised, HiDef will provide marine ornithological and marine mammal design-based density and abundance estimates for context but will not take these forward into the assessment process for Llŷr. Design-based estimates for each relevant species have already been derived (including non-identified animals[1] and addressing availability bias[2]) and provided to NRW (A) as Appendix D on the proposed marine ornithological assessment methodology paper (issued 2 March 2023) and as Tables 3-4 to 3-7 in the marine mammal assessment methodology paper (issued 3 March 2023).

Design-based analysis methods use individual transects as samples whereas model-based methods, such as inlabru (Bachl *et al.*, 2019) and MRSea (Scott-Hayward *et al.* 2014), divide each transect into short segments and model the spatial relationship of detections on these segments with environmental covariates that might influence the distribution of the animals. Consequently, model-

[1] Apportionment of Unidentified Birds, Section 4.2 of NRW advice on DAS, dated 17 February 2023.

[2] Availability Bias, Section 4.3 of NRW advice on DAS, dated 17 February 2023.

based methods can usually generate more robust density and abundance estimates (i.e. tighter confidence intervals) than design-based analysis because changes in the data are better explained at a finer scale than the transect.

For this key reason, HiDef recommend that a model-based approach be taken to Llŷr data analysis (please see Section 3).

2.1. Survey coverage

Survey coverage across UK offshore wind farms tends to be a minimum of 10% and this has been achieved in all the Llŷr surveys except for the one on 5 January 2022. To date, 10% has been considered sufficient for the purpose of baseline characterisation, however, further dialogue around survey purpose and resulting survey design will be helpful between SNCBs and DAS data providers (ourselves and APEM) in light of recent publication of SNCB guidance (as referenced above).

This is longer-term dialogue best carried out strategically and co-ordinated across all the relevant parties; it will not be completed in time to inform the Llŷr project assessment but could potentially be picked up in any discussion of post-consented monitoring (depending on project consent).

2.1.1. Investigating precision in design-based estimates

HiDef have not yet undertaken a comprehensive analysis of the two vs. four camera issue raised by NRW, and not for the seabird species involved at Llŷr. HiDef have undertaken some initial work to investigate the effects of different numbers of camera on precision of estimates for Natural England in relation to an offshore wind development. Whilst intuitively, higher survey coverage should result in improved precision of density estimates (lower coefficient of variation (CV) and tighter 95% confidence intervals), the relationship has thus far shown not to be straightforward. The general inverse relationship between survey coverage and CV (Rexstad and Buckland, 2009) is not always linear or infinite. The resultant CVs are dependent on the nature and abundance of the species of interest, and is particularly challenging for highly clumped distributions.

If there is a consensus amongst SNCBs that they would like this matter to be investigated further, then it can be co-ordinated and progressed separate to project-specific discussions. Agreement will be needed on how best to approach such a targeted study and to select an appropriate survey programme or programmes (offshore wind or other) where it might best be investigated. It would also be worthwhile making sure the action is captured on the various collations of industry research activity such as the Offshore Wind Environmental Evidence Register (OWEER)[3].

NRW (A) have also made a suggestion that using a smaller sampling unit for bootstrapping (say 500m segments rather than the full transect length) may help to improve precision in design-based estimates. Whilst this may be worth investigating it would be part of longer-term work to progress as part of this wider discussion with SNCBs. The main issue in undertaking this approach for design-based estimates, is that it would introduce autocorrelation in the data, which is avoided when the "transect" is the sampling unit. Modelling methods inherently account for autocorrelation and hence our advice to use this approach on Llŷr.

For example, it is worth noting that in previous correspondence with Natural England (regarding Burbo Bank Extension, dated 05 April 2019), HiDef advised *against* using 1 km segments as independent bootstrapping units as they would be highly autocorrelated. This would also be the case for smaller sized segments. The 1 km scale (and below) is likely too small without spatially modelling for species of interest detected in digital aerial surveys for both a raw data and biological perspective. This is

[3] OWEER; Offshore Wind Environmental Evidence Register 2021, JNCC, Offshore Wind Evidence and Change Programme, Offshore Wind Environmental Evidence Register | Marine Data Exchange

because the spatial scale which draws birds to foraging locations operates on much larger scales than 1 km. Gulls, gannets and kittiwakes, for example, can detect foraging aggregations of conspecifics from many kilometres away. Additionally, migrating or moving flocks of birds can span multiple kilometres at certain times of the year. Arguably, the appropriate sampling unit for a transect based survey design is the transect (e.g. Anderson *et al.* 1979). 1 km segments are highly unlikely to be independent sampling units. To not take account of spatial autocorrelation when carrying out such an analysis would likely result in an underestimate of the variance in the data, giving a false impression of the resulting precision of abundance estimates. These effects can be taken account of in modelling, such as using inlabru or MRSea

2.1.2. Cable corridor

As for Erebus, no DAS has been undertaken for the Llŷr cable corridor search area. To clarify the information provided in the Scoping Report, survey work was carried out for the **Llŷr Development Area + 4km buffer** within which the two Array Areas (Llŷr 1 and Llŷr 2) are proposed. The survey area is shown by Figure 2-1 in the survey summary paper (HiDef, 2023; issued 20th January).

It is unclear how any DAS survey would be designed for a smaller (narrower) cable corridor area and how the environmental gradients in operation from shore to sea could properly be accounted for. Survey of the cable corridor in isolation is of very little help if there is no wider DAS of Skomer, Skokholm and seas off Pembrokeshire Special Protection Area (SPA) against which data can be compared. Even if it had been collected, DAS data would not have been at the scale, or have had the necessary resolution or certainty/precision, to be able to inform route selection.

Nor is quantitative analysis possible (or usually requested) for very short-term seabird disturbance arising from ground preparation or cable-laying activities within the cable corridor. Potential impacts from these activities are considered qualitatively in assessment and have no long-term population consequences associated with them; they can readily be mitigated even within an SPA through adoption of good practice working methods.

Additionally, no obvious concerns or suggestions arising from the cable-laying assessment undertaken for Erebus in respect of marine ornithology or marine mammals were apparent in the Erebus consent. If NRW (A) do have concerns for Llŷr then please let us know and we can take them on board for the assessment.

3. Spatial modelling for Llŷr: inlabru method statement

As advised, HiDef will be basing the Llŷr project assessment on model-based density and abundance estimates for marine ornithology and marine mammal interests. Our recommended modelling approach for Llŷr is to use inlabru (Bachl F. E., Lindgren, Borchers, & Illian, 2019) as described and discussed in more detail below.

3.1. Background

MRSea has been developed as a statistical modelling package in the R software for analysing animal survey data for signs of changes in animal distribution and abundance following marine renewables development (Scott-Hayward, *et al.*, 2014). It has been the primary spatial modelling method for obtaining animal abundance and density predictions for offshore wind environmental impact assessments. However, HiDef have encountered some issues when using MRSea which have limited analyses, such as inflexibility in model-fitting and lack of community support for coding issues, and have, therefore, been investigating other approaches.

HiDef have been applying spatial models of species density through the ‘inlabru’ R package. The inlabru approach extends the classes of generalised additive model (GAM)-like models, that are also the basis of MRSea. It builds on the widely used R-INLA, which utilises integrated nested Laplace approximation (INLA) to carry out Bayesian inference (Rue, *et al.*, 2009). Although the statistical approaches behind MRSea and inlabru are different, the results obtained are comparable. Like MRSea, inlabru can be used to fit models with or without environmental covariates to spatial data, run model diagnostics, plot density surfaces, make predictions, and calculate uncertainty about these predictions (Scott-Hayward, *et al.*, 2014; Bachl, *et al.*, 2019). It is a capable alternative to MRSea, with faster computation times, more accurate results for small sample sizes, and a wider range of uses (Keogan, *et al.*, 2022).

3.2. Introducing inlabru

3.2.1. A new approach for generating spatial density surfaces

The inlabru package is a collaborative project between the University of St Andrews and the University of Edinburgh and provides ecologists with easier access to Bayesian inference from spatial point processes, spatial counts, gridded and georeferenced data (Bachl F. E., Lindgren, Borchers, & Illian, 2019). It allows users to model species distribution and estimate density and abundance with a variety of data types, such as complete spatial maps of the locations of individuals or groups, counts in plots, points, and distance sampling data (Bachl F. E., Lindgren, Borchers, & Illian, 2019).

Bayesian inference is becoming more frequently used in ecology due to its ability to account for hierarchical structure, as well as uncertainties around observations and processes inherent in ecological systems (Ellison, 2004; Banner, Irvine, & Rodhouse, 2020). Bayesian approaches differ from frequentist methods in several ways, with the main difference being that parameters are treated as random variables instead of fixed, "true" quantities (Ellison, 2004). The use of random variables as parameters requires careful consideration to ensure that the specification of probability distributions reflect previous “a priori” knowledge about parameter uncertainty and existing data (Banner, Irvine, & Rodhouse, 2020). A prior distribution is the probability that would express the user’s beliefs about this quantity before evidence is examined.

Therefore, in Bayesian analysis, prior distributions are specified from current knowledge, and are combined with observed data to obtain a posterior distribution of results, which is defined as the revised or updated probability of an event occurring after considering new information (Hayes, 2021). Thus, the Bayesian approach is opposed to frequentist methods where only the data is used to conduct analysis, and no prior knowledge is taken into consideration.

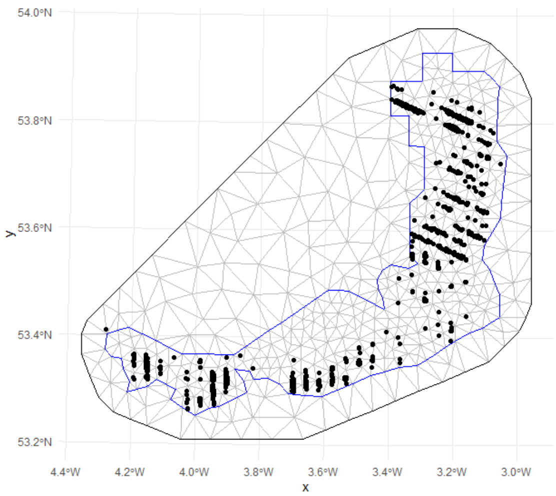
Like MRSea, inlabru models the relationship between observations and a suite of environmental covariates to predict density throughout the area of interest. The inlabru package can fit a variety of different models, such as binomial, exponential, or zero-inflated Poisson models. However, the most common models fitted in inlabru are log Gaussian Cox processes (LGCPs) as they are used for identifying spatial variation and autocorrelation, which occur in many spatial datasets. It is used alongside the stochastic partial differential equation (SPDE) approach, which accounts for autocorrelation in data.

For inference, inlabru uses the INLA Bayesian approach as it is an accurate and fast alternative to Markov chain Monte Carlo (MCMC) methods for fitting models with unobserved, normally distributed random variables (Rue, Martino, & Chopin, Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations (with discussion), 2009; Bachl F. E., Lindgren, Borchers, & Illian, 2019). See **Error! Reference source not found.** for a more detailed statistical background of inlabru.

3.2.2. Meshes for model-fitting

inlabru approximates continuous space using triangular tiles in the form of a “mesh”, which is used to fit models and make density and abundance predictions (Bachl F. E., Lindgren, Borchers, & Illian, 2019). An example of a mesh is shown in Figure 3-1.

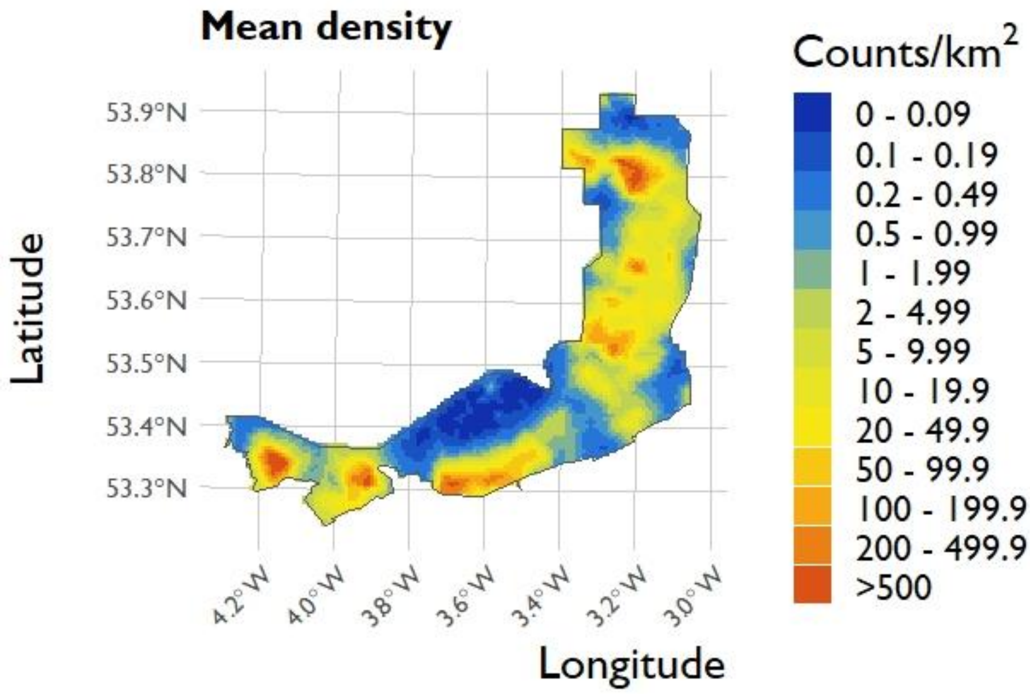
Figure 3-1. A "mesh" for spatial data. The black points show the observations for the species, the blue line shows the survey region, and the black line shows the outer boundary which acts as a "buffer" for models, to reduce interference between the points and the boundaries. See the R-INLA documentation for more information (Rue, Martino, & Chopin, R-INLA Project, 2009).

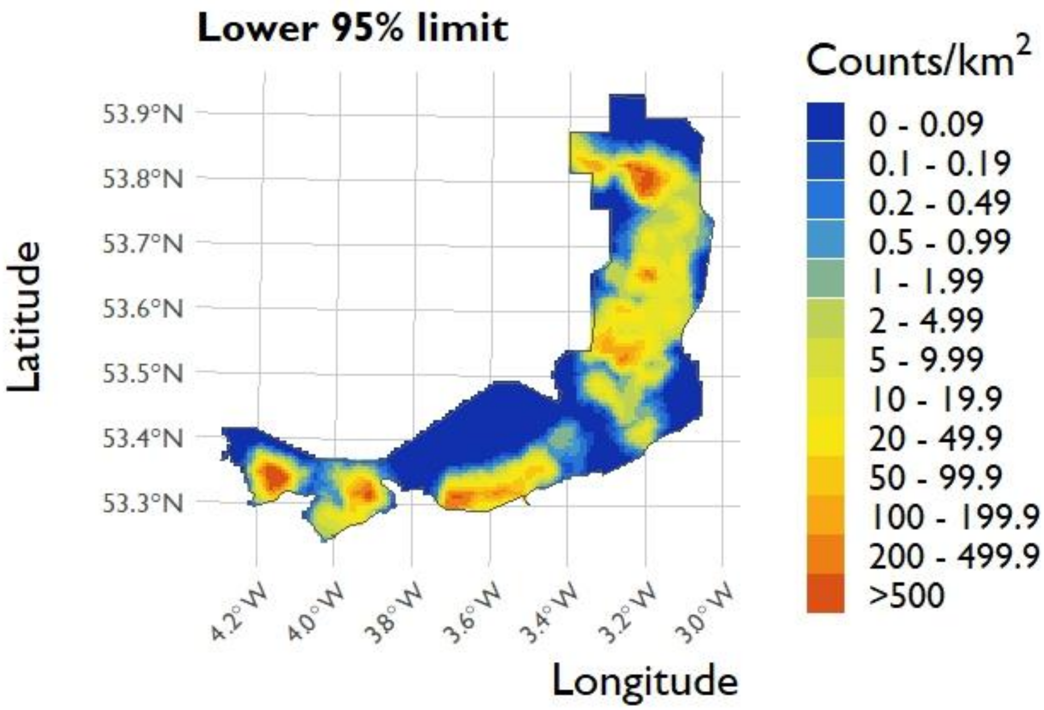


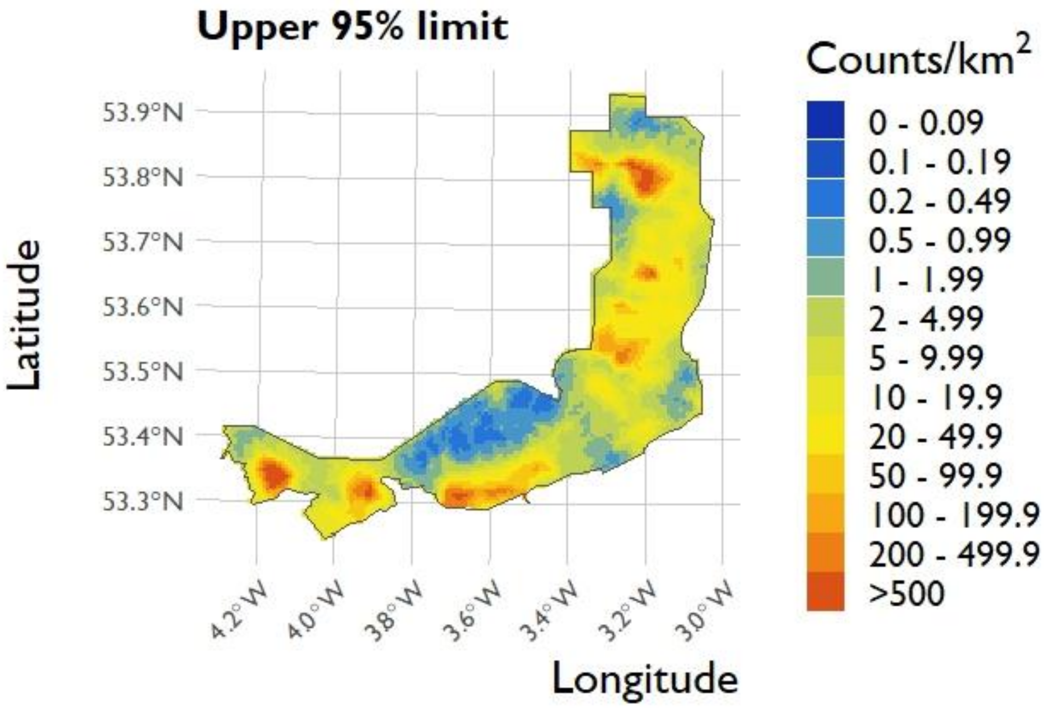
3.2.1. Inlabru model outputs

Like with MRSea, inlabru can produce density surface maps to display results from the models. These density surface maps show the density estimates across the whole survey area and can also be cropped to display a sub-section from smaller boundaries of the survey area. Figure 3-2 is an example of what a density surface map from inlabru looks like. It shows the density estimate for the species of interest with the estimated animal counts per km^2 for the whole survey area.

Figure 3-2. Mean, lower and upper credible intervals for density estimates for a species of interest within the survey region.



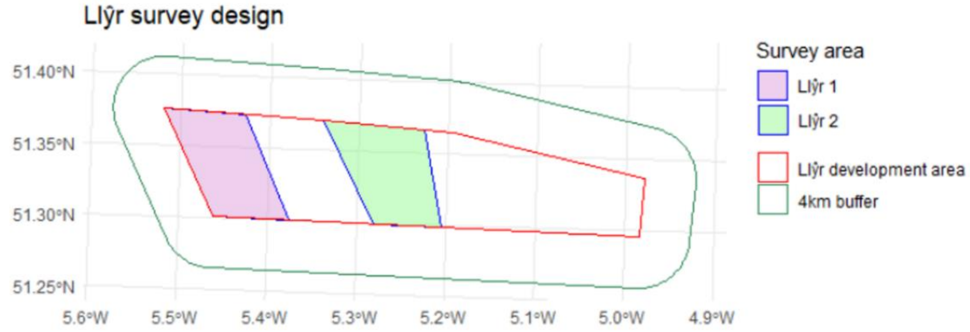



Upper 95% limit
Counts/km2
0 - 0.09
0.1 - 0.19
0.2 - 0.49
0.5 - 0.99
1 - 1.99
2 - 4.99
5 - 9.99
10 - 19.9
20 - 49.9
50 - 99.9
100 - 199.9
200 - 499.9
>500
53.9°N
53.8°N
53.7°N
53.6°N
53.5°N
53.4°N
53.3°N
Latitude
4.2°W
4.0°W
3.8°W
3.6°W
3.4°W
3.2°W
3.0°W
Longitude

3.3. Llŷr approach

For the Llŷr project, the data will be modelled for the larger survey area plus a 4 km buffer, to account for missing transects (e.g., January 2022) and low sample sizes from the smaller sites. The abundance estimates will then be extracted from the overall survey area corresponding to the predictions for the smaller Llŷr array sites 1 and 2, with and without the required buffers. Figure 3-3 shows a map of the smaller sites 1 and 2 within the overall survey area and a 4 km buffer.

Figure 3-3. A map of the smaller Llŷr *sites 1 and 2 within the overall survey area (development area inside a 4 km buffer)*



The bird species of interest to the proposed Llŷr Project are:

- kittiwake (*Rissa tridactyla*),
- lesser black-backed gull (*Larus fuscus*),
- guillemot (*Uria aalge*),
- razorbill (*Alca torda*),
- puffin (*Fratercula arctica*),
- manx shearwater (*Puffinus puffinus*), and
- gannet (*Morus bassanus*);

and the marine mammal species are:

- common dolphin (*Delphinus delphis*), and
- harbour porpoise (*Phocoena phocoena*).

The data for seabirds and marine mammals will be pooled into their respective individual seasons and years to account for surveys with low sample sizes. Models will be fitted to each month/season/year and predictions will be made depending on the species. For cetaceans, mean density surfaces and abundance estimates will be made for each season (summer / winter) and year, and for the overall data set with observations from all 24 surveys. This differs to seabirds, where a temporal model will be fitted to each year, and density surfaces and abundance estimates will be made for *each individual survey* using these temporal models. This will still allow for the calculation of mean seasonal peaks as required for the assessment of displacement.

All unidentified birds or marine mammals recorded in a category (e.g., large auk) will be apportioned to species (termed 'non-ID apportioning') based on the ratio of identified species within that category in that survey (e.g., guillemot and razorbill). Both unapportioned and apportioned data can be analysed in inlabru in the same way. Availability bias corrections will be applied to guillemot, razorbill, puffin, harbour porpoise and common dolphin.

Environmental covariates will be included in the models to identify whether they influence the density and abundance estimates and will be removed from the models if there is no significant effect. The environmental covariates that are available to be used include bathymetry, sea surface temperature, and seabed sediment.

HiDef's data science team will be conducting analysis for the Llŷr project. The team has experience working with aerial survey data and fitting spatial models in inlabru to obtain abundance estimates and density surfaces for survey areas, for example in Keogan, *et al.* (2022), Olley (2022), Peters-Grundy, *et al.* (2022), and with the approval of NatureScot have fitted to marine mammal data at a site off Scotland. We also have regular contact with the developers of inlabru, as well as staff in BioConsult (Vilela *et al.*, 2021) and Biotope who have experience using inlabru and can call on them for support if necessary.

3.4. Benefits of using inlabru

Bayesian approaches are most used for estimating species richness and abundance from geographically or logistically constrained samples, or in response to expected environmental change (Ellison, 2004). In inlabru, the most common models for abundance estimates are fitted using Gaussian random fields (GRFs) and the SPDE approach to implement LGCPs for univariate and spatial point processes based on ecological survey data (Bachl F. , Lindgren, Borchers, & Illian, 2018)https://cran.r-project.org/web/packages/inlabru/readme/README.html.

These point process models also account for spatial autocorrelation through the use of this GRF and SPDE approach. inlabru is an extension to MRSea's GAM approach with spatially adaptive smoothing, as it uses more general nonlinear predictor expressions. Therefore, inlabru can be applied to a variety of terrestrial and marine exercises, instead of MRSea, which was developed specifically for the offshore wind industry in the UK (Keogan, et al., 2022). inlabru enables users to apply Bayesian methods to spatial data which was challenging before it was released. Now, non-specialist users can apply Bayesian methods with inlabru without needing to understand the complex statistical background behind it (Bachl F. E., Lindgren, Borchers, & Illian, 2019). An advantage of using Bayesian inference is that it can account for hierarchical structure, as well as uncertainties around observations and processes inherent in ecological systems (Ellison, 2004). The ability to specify prior distributions and determine model parameters from current knowledge is another benefit of Bayesian methods, as the data can be combined with knowledge of previous results and findings, rather than just relying on the data itself.

inlabru can fit models to a variety of different data types like spatial counts data or point data. The function lgcp() is specifically used for fitting LGCPs, which are suitable for modelling spatial point process data where there is observed or unobserved environmental variation (Møller, Syversveen, & Waagepetersen, Log Gaussian Cox processes, 1998; Møller & Waagepetersen, Modern statistics for spatial point processes (with discussion), 2007). The function bru() is more general and can be used to fit various models like Poisson and binomial models for example, as well as models with joint likelihoods, which are used for marked point processes. In addition to fitting these models, the user can incorporate environmental covariates and fit temporal models using inlabru, as well as SPDE-only models. This is useful for more in-depth analysis to discover trends over space and time, and to determine whether certain environmental conditions influence the results.

Both MRSea and inlabru can be used to obtain abundance estimates and the mean, median, standard deviation, and quantiles of these estimates. inlabru uses a prediction method based on fast Monte Carlo sampling, which allows posterior prediction of general expressions of the latent variables (i.e., variables that cannot be measured directly). This produces a posterior distribution, which is defined earlier as the revised or updated probability of an event occurring after considering new information (Bachl F. , Lindgren, Borchers, & Illian, 2018; Hayes, 2021). This is compared to MRSea's model outputs which are used in the bootstrapping function from which we can calculate the mean, median, standard deviation, and quantiles. Model-fitting in inlabru is generally computationally efficient, and the time taken has been found to be around three times quicker than MRSea (Keogan, et al., 2022).

inlabru is becoming more widely used for offshore wind farm assessments in Europe, such as in the technical report for THOR offshore wind farm environmental investigations, which found similar advantages to using the inlabru method and Bayesian inference (Vijela & Schütte, 2021). It has also been applied to passive accoustic monitoring (PAM) data in the Moray Firth to model porpoise occurrence (Williamson, et al., 2021). Another example is its use for fitting point process models to analyse spatio-temporal distance sampling data, to compute density and abundance estimates (Yuan, et al., 2017).

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FLOVENTIS ENERGY

LLŶR FLOATING OFFSHORE WIND PROJECT

LLŶR

MARINE ORNITHOLOGY

Comparison of Model (inlabru) and Design-Based Estimates

Prepared by: HiDef Aerial Surveying Ltd

June 2023

Acronyms, Abbreviations and Units

Acronym, Abbreviation or Unit	Definition	Acronym, Abbreviation or Unit	Definition
CRM	Collision Risk Modelling		
HiDef	HiDef Aerial Surveying Ltd		
JNCC	Joint Nature Conservation Committee		
km	Kilometre		
km^2	Squared kilometre		
MSP	Mean Seasonal Peak		
NRW	Natural Resources Wales		
SD	Standard Deviation		

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1. Introduction

At the Llŷr marine ornithology stakeholder meeting held on 24th May 2023, Natural Resources Wales (NRW) and Joint Nature Conservation Committee (JNCC) requested this comparison paper of model-based (inlabru) and design-based density and abundance estimates for all relevant seabird species (scoped in for quantitative assessment) recorded during the digital aerial survey programme undertaken by HiDef Aerial Surveying Ltd (HiDef) for the project (Note that a sister paper is being provided for marine mammals).

The seven seabird species addressed in this comparison paper are: black-legged kittiwake (hereafter 'kittiwake'), lesser black-backed gull and northern gannet (hereafter 'gannet') (in relation to collision risk modelling or 'CRM') and common guillemot (hereafter 'guillemot'), razorbill, Atlantic puffin (hereafter 'puffin'), Manx shearwater and gannet (in relation to displacement assessment).

Modelling of the survey data (for the full survey area) has been conducted using Bayesian Point Processing available through the R-statistical package 'inlabru'. A full description and method statement is presented in the HiDef paper issued 16th March 2023: "HiDef advice to NRW on design and model-based analysis methods". This was followed by a presentation at the 24th March 2023 meeting from the two data scientists (from HiDef and DMP Stats) who carried out the inlabru modelling for Llŷr.

This paper presents a comparison only of the figures that are being input into quantitative assessment. For CRM this is the monthly densities of flying birds recorded within the wind farm footprint and in relation to displacement analysis it is the monthly estimates of abundance of 'all birds' (flying and sitting) recorded in the area of the windfarm footprint plus 2 km buffer (these are used to derive the mean seasonal peak (MSP) population estimates on which displacement matrices are based).

So, the comparison and discussion of inlabru and design-based analysis methods given in this paper is undertaken on the basis of these figures.

All the inlabru and design-based estimates include the apportioning of unidentified birds and estimates for auk species (guillemot, razorbill, puffin) are corrected for availability bias.

As advised at the meeting, HiDef recommend that it is the inlabru estimates of density and abundance that are fed through into the quantitative assessments required for project Llŷr. HiDef consider these to be the more robust option given their generally narrower confidence (credible) limits and their ability to be informed by the spatial locations of birds throughout the survey area. The design-based analysis undertaken does confirm that there can be confidence taken in the modelled inlabru estimates as the two sets of figures correspond closely.

1.1. Kittiwake

The maximum design-based and model-based density estimates of flying kittiwakes in the Llŷr 1 Array Area were recorded in the autumn migration, with 7.09 birds/km^2 (5.96 SD; October 2021) and 7.34 birds/km^2 (1.21 SD; October 2021), respectively (**Figure 1-1.**). Overall, numbers were relatively consistent, with modelling yielding slightly larger estimates in comparison to design-based estimates. The largest discrepancy occurred in November 2021, and this is likely due to the model being informed by the spatial locations of birds across the entirety of the Llŷr Marine Ornithology Survey Area, with high densities occurring in the north-west corner of the Llŷr 1 Array Area as well as to the south (**Figure 1-2 and Figure 1-3**). However, the model-based estimate is within the upper 95% confidence interval of the design-based estimate.

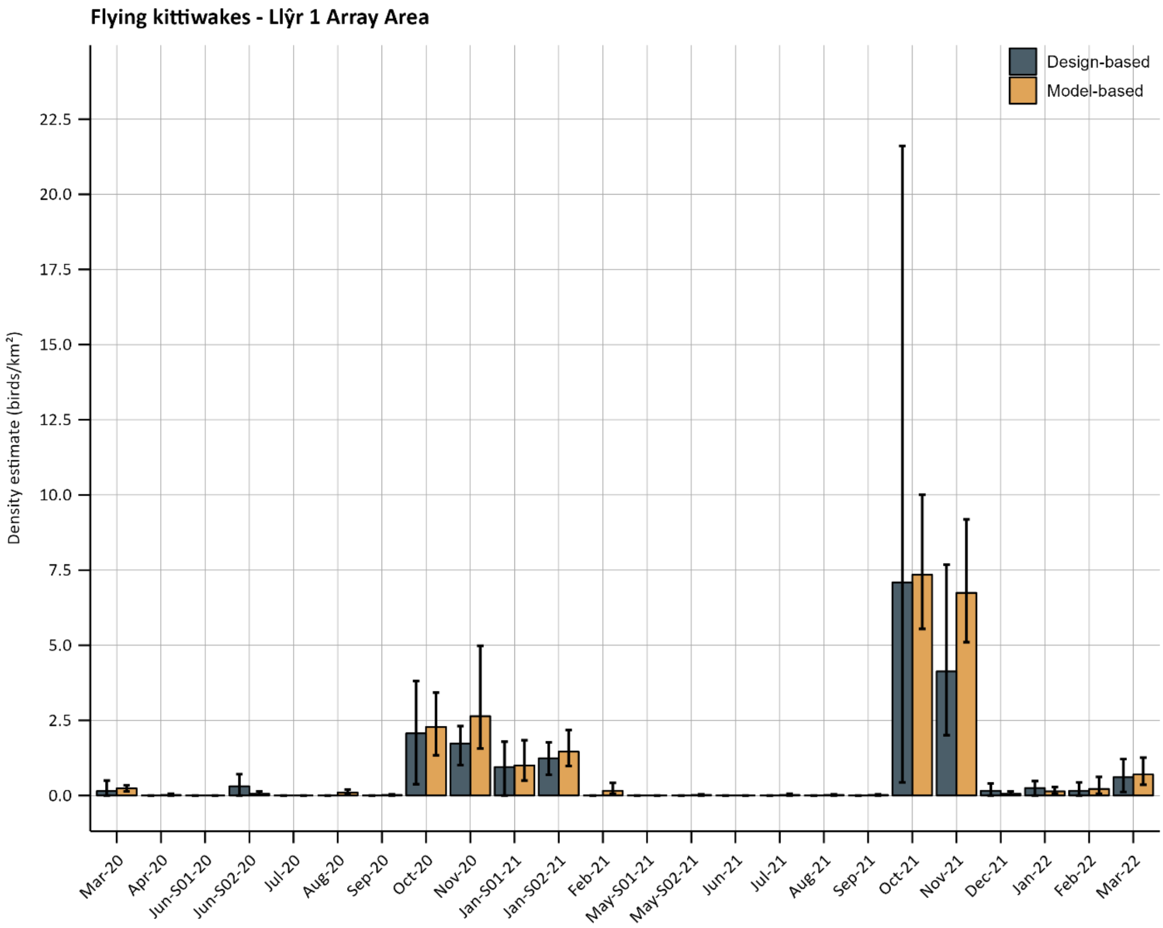

Figure 1-1. Monthly design-based and model-based density estimates of flying kittiwakes within the Llŷr 1 Array Area between March 2020 and March 2022. Associated confidence intervals (design-based) and credible intervals (model-based) are represented by error bars

Figure 1-2. Distribution map of recorded flying kittiwakes within the Llŷr Marine Ornithology Survey Area in November 2021. Note that due to red line boundary refinement only Llŷr 1 will be progressed to Application.

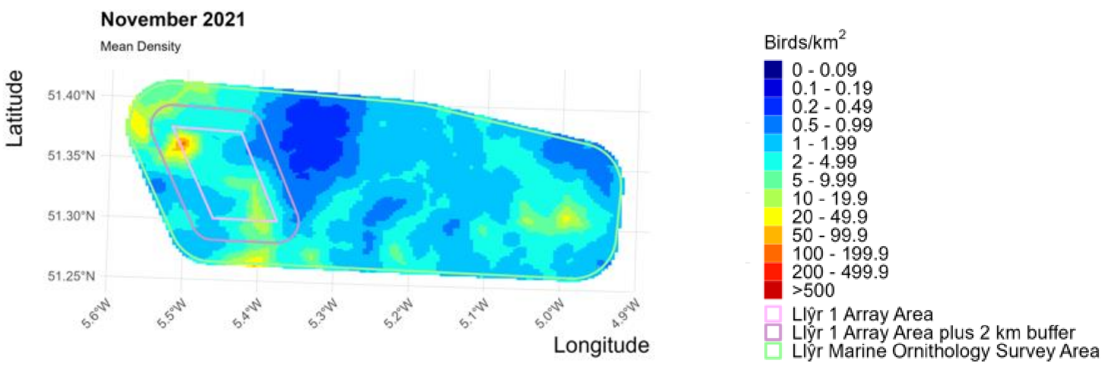

Figure 1-3. Mean model-based density surface for flying kittiwakes in the Llŷr Marine Ornithology Survey Area in November 2021

1.2. Lesser black-backed gull

The maximum design-based and model-based density estimates of flying lesser black-backed gulls in the Llŷr 1 Array Area were recorded in the spring migration and breeding season with 0.44 birds/km^2 (0.46 SD; March 2022) and 0.16 birds/km^2 (0.08 SD; June S01 2020), respectively (

Figure 1-4). Overall, model-based and design-based estimates were quite varied throughout the survey period, with design-based yielding larger estimates in some months and model-based in others. The largest discrepancies between the design and model-based estimates occurred in May S01 2021 and March 2022, with the design-based estimating higher densities. The modelling is informed by the spatial locations of birds throughout the Llŷr Marine Ornithology Survey Area and makes spatially explicit predictions of density (**Figure 1-5 and Figure 1-6**). The design-based estimator is a simple mean of bootstrap resamples of density and very high counts on one transect will lead to positive bias in the mean density estimate.

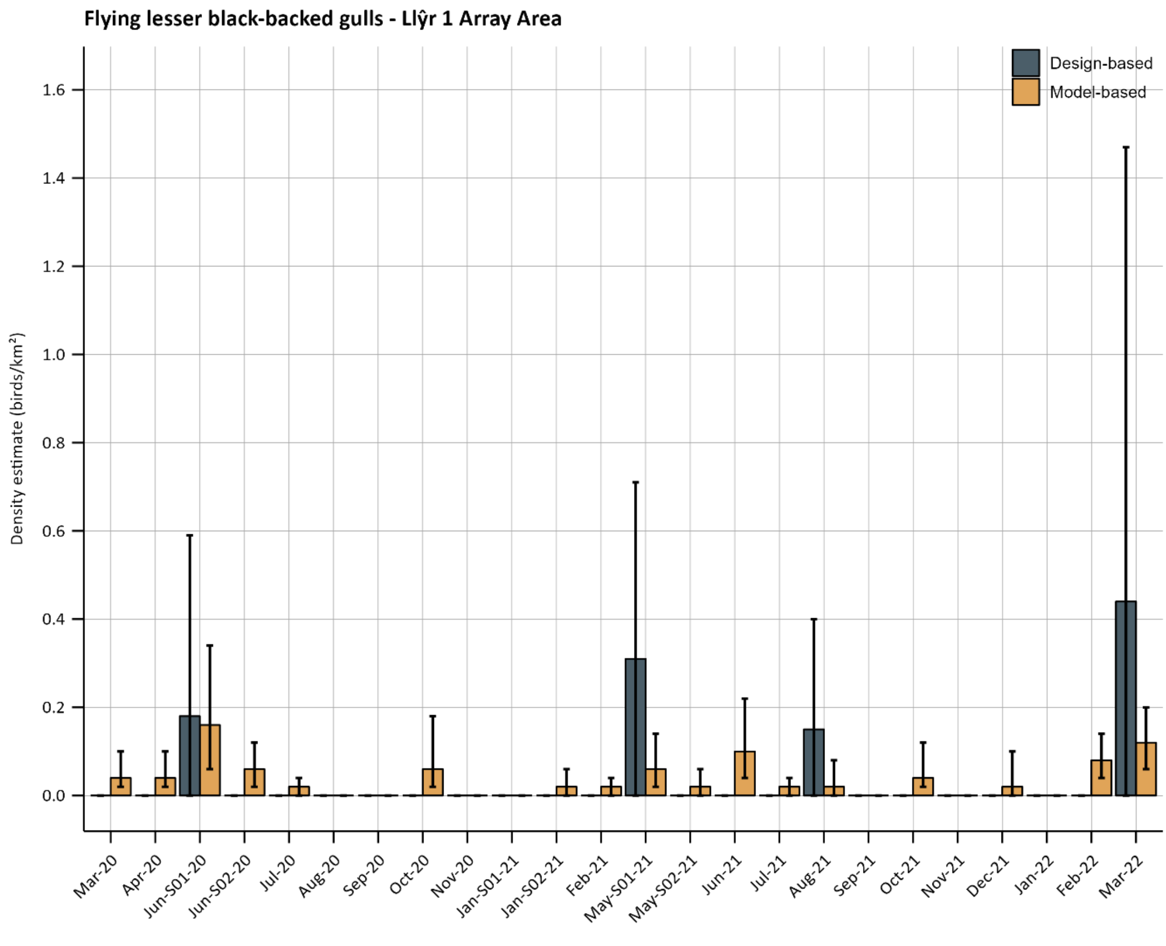

Figure 1-4. Monthly design-based and model-based density estimates of flying lesser black-backed gulls within the Llŷr 1 Array Area between March 2020 and March 2022. Associated confidence intervals (design-based) and credible intervals (model-based) are represented by error bars

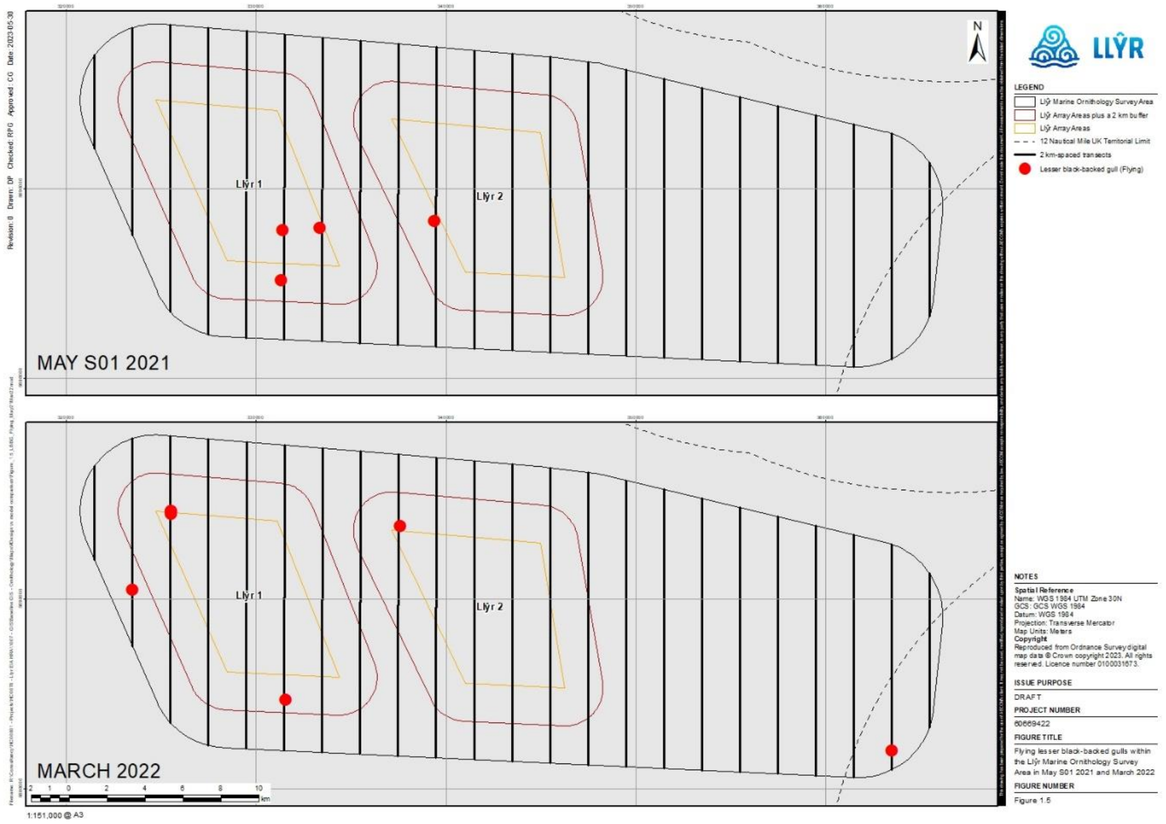

Figure 1-5. Distribution map of flying lesser black-backed gulls within the Llŷr Marine Ornithology Survey Area in May S01 2021 and March 2022. Note that due to red line boundary refinement only Llŷr 1 will be progressed to Application.

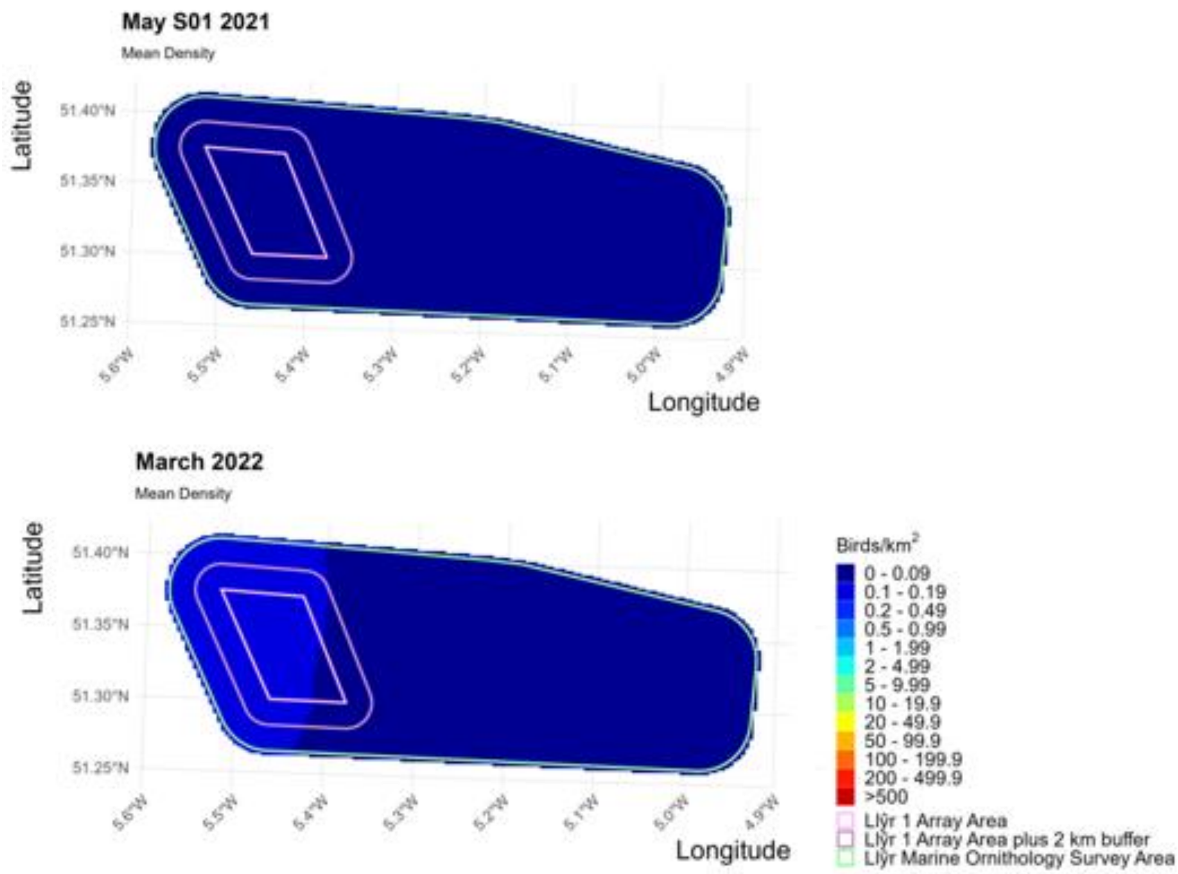

Figure 1-6. Mean model-based density surface for flying lesser black-backed gulls in the Llŷr Marine Ornithology Survey Area in May S01 2021 and March 2022

1.3. Guillemot

The maximum design- and model-based population estimates in the Llŷr 1 Array Area plus a 2 km buffer were recorded in the non-breeding season, with 17,209 birds (95% CI 11,981 – 23,474; October 2020) and 17,838 birds (95% CI 16,819 – 18,970; October 2020), respectively (**Figure 1-7**). Overall, model-based estimates yielded similar population estimates to design-based estimates, albeit with smaller credible intervals.

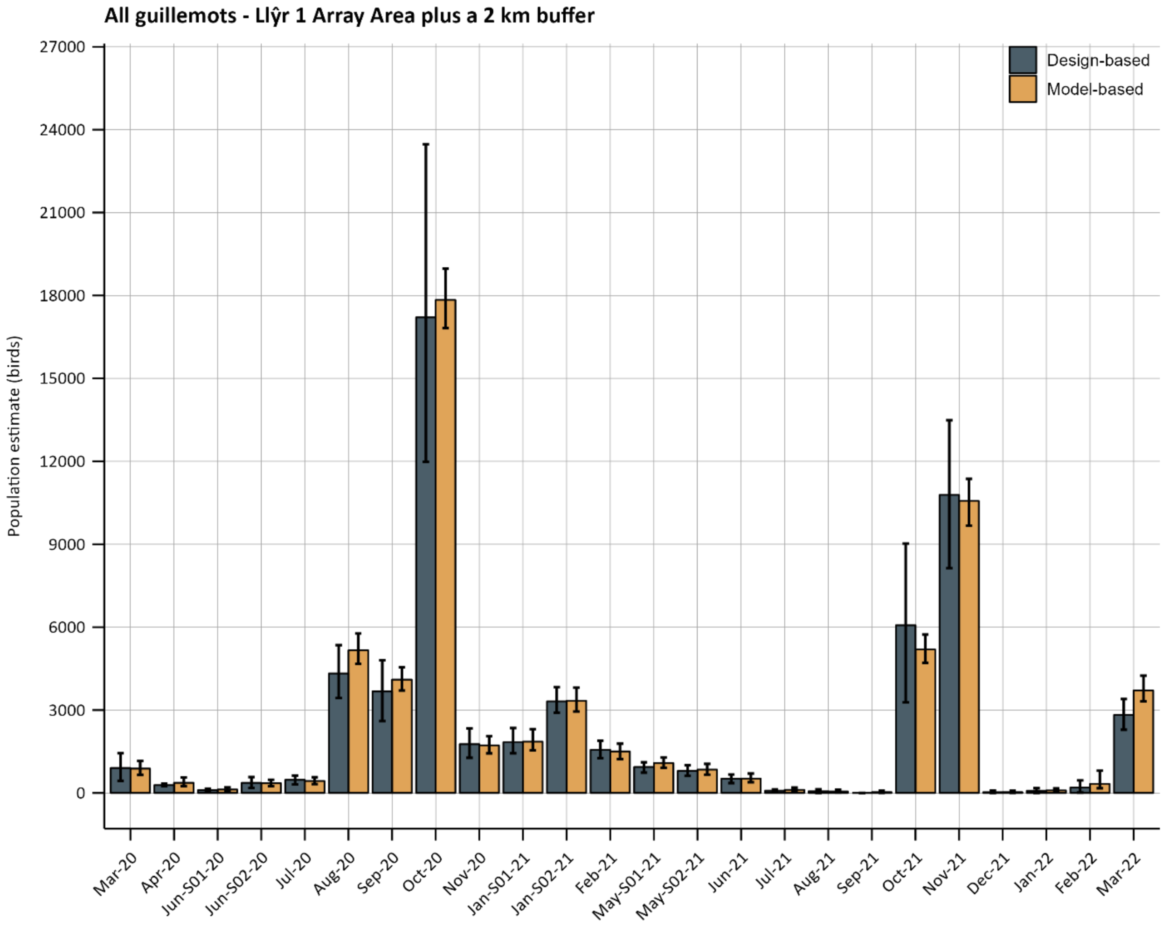

Figure 1-7. Monthly design-based and model-based population estimates of all guillemots (flying and sitting) within the Llŷr 1 Array Area plus a 2 km buffer between March 2020 and March 2022. Associated confidence intervals (design-based) and credible intervals (model-based) are represented by error bars

Across the Llŷr 1 Array Area plus a 2 km buffer, the design-based and model-based non-breeding season MSP was considerably higher than the breeding season (**Table 1-1**). MSPs were generally lower using the design-based method compared to the model-based method. However, the point estimates of density from each method generally sat within the confidence/credible intervals of the other, indicating that the estimates are effectively the same.

Table 1-1. Comparison of design-based and model-based mean seasonal peak population estimates of all guillemots (flying and sitting) in each season within the Llŷr 1 Array Area plus 2 km buffer between March 2020 and March 2022

Guillemot	Population estimate (number) (design / model)	Lower 95% confidence / credible limit (number) (design / model)	Upper 95% confidence / credible limit (number) (design / model)
Llŷr 1 Array Area plus 2 km buffer			
Breeding season	1,866 / 2,295	1,332 / 1,045	2,400 / 3,547
Non-breeding season	13,996 / 14,202	9,309 / 10,113	18,683 / 18,290

1.4. Razorbill

The maximum design-based and model-based population estimates in the Llŷr 1 Array Area plus a 2 km buffer were recorded during the autumn migration period, with 2,828 birds (95% CI 1,095 – 4863; October 2021) and 2,478 birds (95% CI 2,056 – 3,034; October 2021), respectively (**Figure 1-8**). Overall, model-based estimates yielded similar population estimates to design-based ones, however model-based estimates produced smaller credible intervals, demonstrating estimates with higher precision.

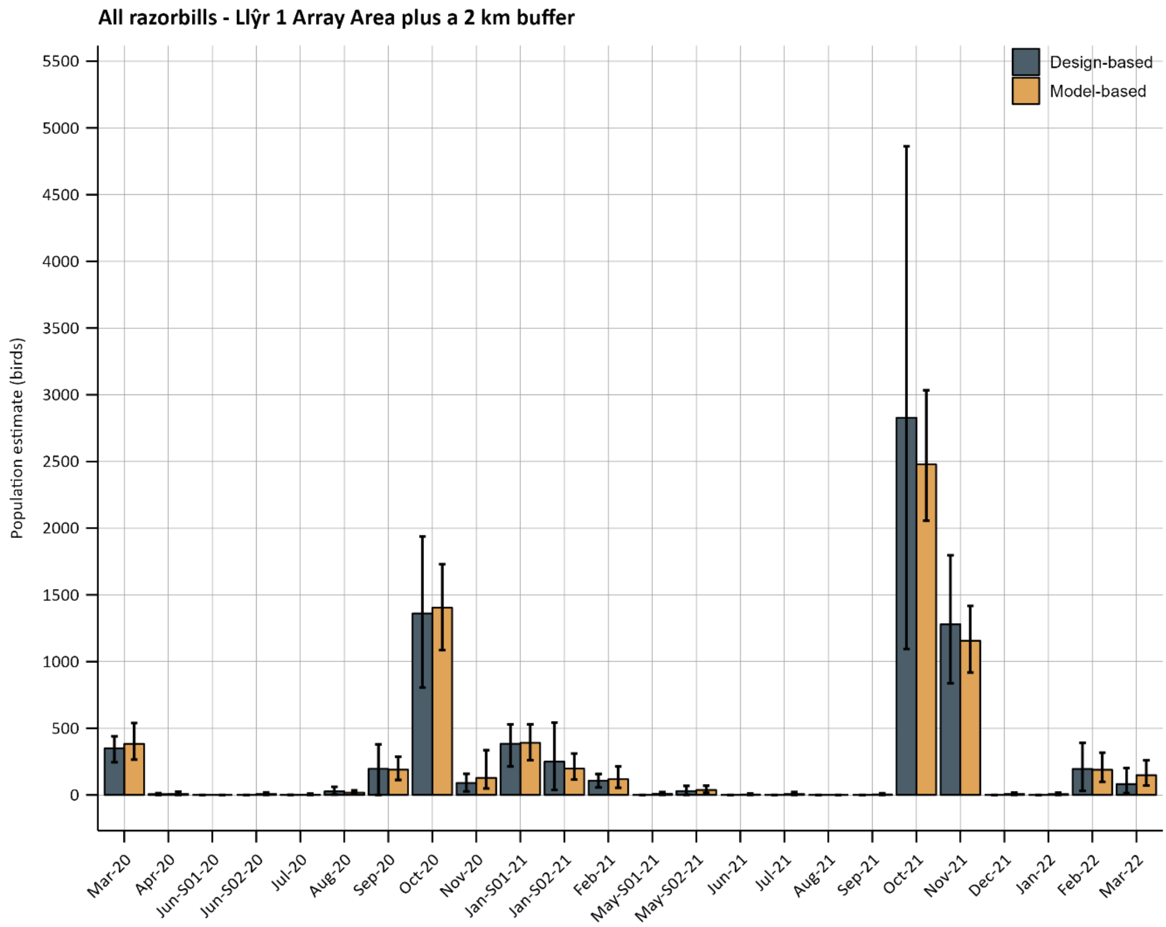

Figure 1-8. Monthly design-based and model-based population estimates of all razorbills (flying and sitting) within the Llŷr 1 Array Area plus a 2 km buffer between March 2020 and March 2022. Associated confidence intervals (design-based) and credible intervals (model-based) are represented by error bars

Across the Llŷr 1 Array Area plus a 2 km buffer, the highest design-based and model-based MSPs were recorded in the autumn migration period (**Table 1-2**). MSPs were slightly lower using the design-based method compared to the model-based method for the breeding and spring migration seasons, but marginally higher for the autumn migration and non-breeding season. However, the point estimates of density from each method generally sat within the confidence/credible intervals of the other, indicating that the estimates are effectively the same. Overall confidence / credible intervals around the MSPs were comparable between both approaches for all seasons except for the spring migration season.

Table 1-2. Comparison of design-based and model-based mean seasonal peak population estimates of all razorbills (flying and sitting) in each season within the Llŷr 1 Array Area plus 2 km buffer between March 2020 and March 2022

Razorbill	Population estimate (number) (design / model)	Lower 95% confidence / credible limit (number) (design / model)	Upper 95% confidence / credible limit (number) (design / model)
Llŷr 1 Array Area plus a 2 km buffer			
Breeding season	18 / 23	2 / 5	44 / 42
Autumn migration	2,094 / 1,941	709 / 695	3,500 / 3,200
Spring migration	272 / 286	125 / 32	420 / 646
Non-breeding season	832 / 774	481 / 151	1,183 / 1,468

1.5. Puffin

The maximum design-based and model-based population estimates in the Llŷr 1 Array Area plus a 2 km buffer were recorded in the non-breeding season, with 1,006 birds (95% CI 603 – 1,341; March 2020) and 1,027 birds (95% CI 843 – 1,248; March 2020), respectively (**Figure 1-9**). Overall, model-based estimates yielded similar population estimates to design-based ones, albeit generally with narrower confidence / credible intervals.

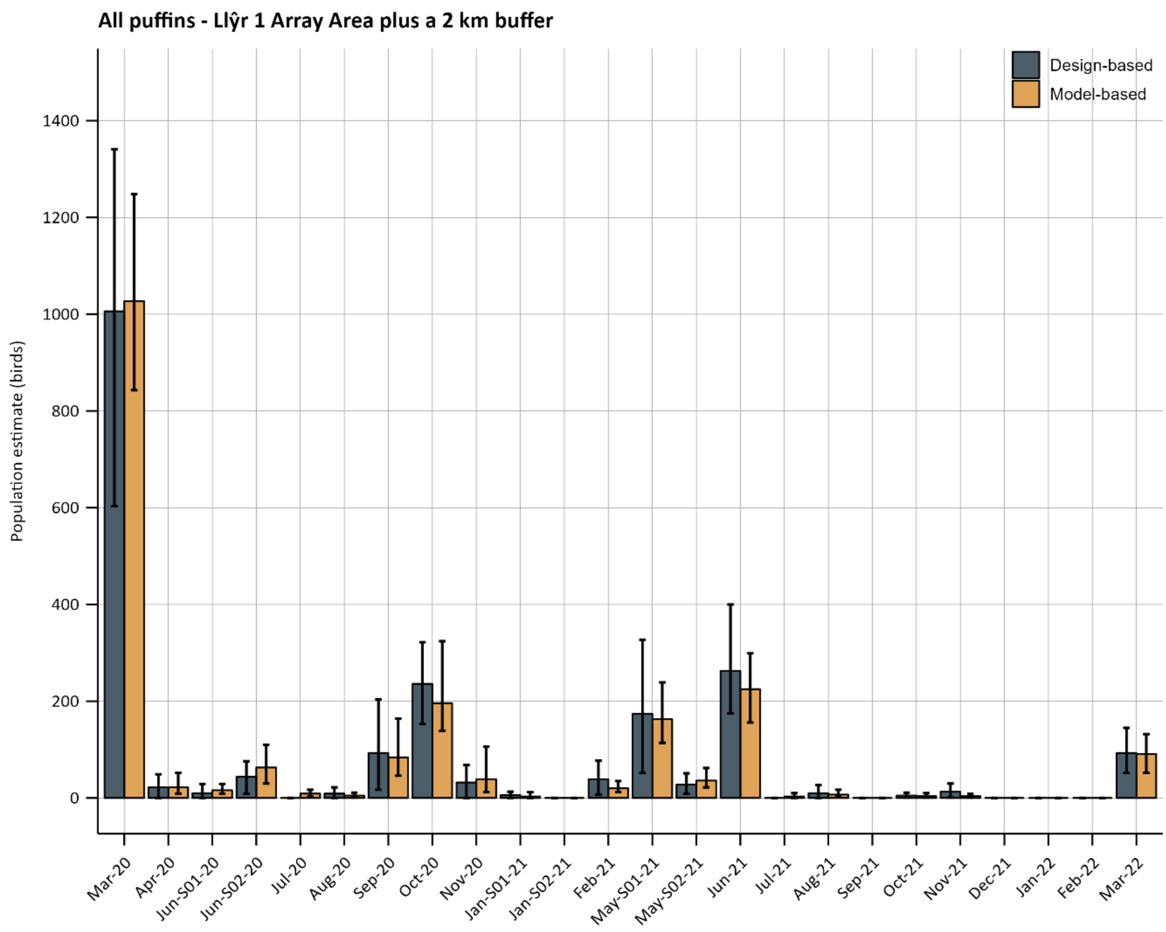

Figure 1-9. Monthly design-based and model-based population estimates of all puffins (flying and sitting) within the Llŷr 1 Array Area plus a 2 km buffer between March 2020 and March 2022. Associated confidence intervals (design-based) and credible intervals (model-based) are represented by error bars

Across the Llŷr 1 Array Area plus a 2 km buffer, the maximum design-based and model-based MSPs were recorded in the non-breeding season (**Table 1-3**). MSPs were similar between both approaches in all seasons. Overall confidence / credible intervals around the MSPs were comparable between both approaches for the breeding season.

Table 1-3. Comparison of design-based and model-based mean seasonal peak population estimates of all puffins (flying and sitting) in each season within the Llŷr 1 Array Area plus 2 km buffer between March 2020 and March 2022

Puffin	Population estimate (number) (design / model)	Lower 95% confidence / credible limit (number) (design / model)	Upper 95% confidence / credible limit (number) (design / model)
Llŷr 1 Array Area plus a 2 km buffer			
Breeding season	154 / 144	69 / 83	239 / 205
Non-breeding season	550 / 559	284 / 407	816 / 711

1.6. Manx shearwater

The maximum design-based and model-based population estimates in the Llŷr 1 Array Area plus a 2 km buffer were recorded in the spring migration and breeding season with 2,192 birds (95% CI 425 – 4641; March 2022) and 4,883 birds (95% CI 3925– 5,995; August 2020), respectively (**Figure 1-10**). Overall, model-based estimates yielded larger population estimates in comparison to design-based estimates, albeit with narrower credible intervals (**Figure 1-10**). The largest discrepancy between the design and model-based estimates occurred in August 2020. This is most likely due to the fact that the modelling is informed by the spatial locations of birds across the entire Llŷr Marine Ornithology Survey Area, with very high densities occurring nearby to the west, just outside of the Llŷr 1 Array Area plus a 2 km buffer area (**Figure 1-11 and Figure 1-12**).

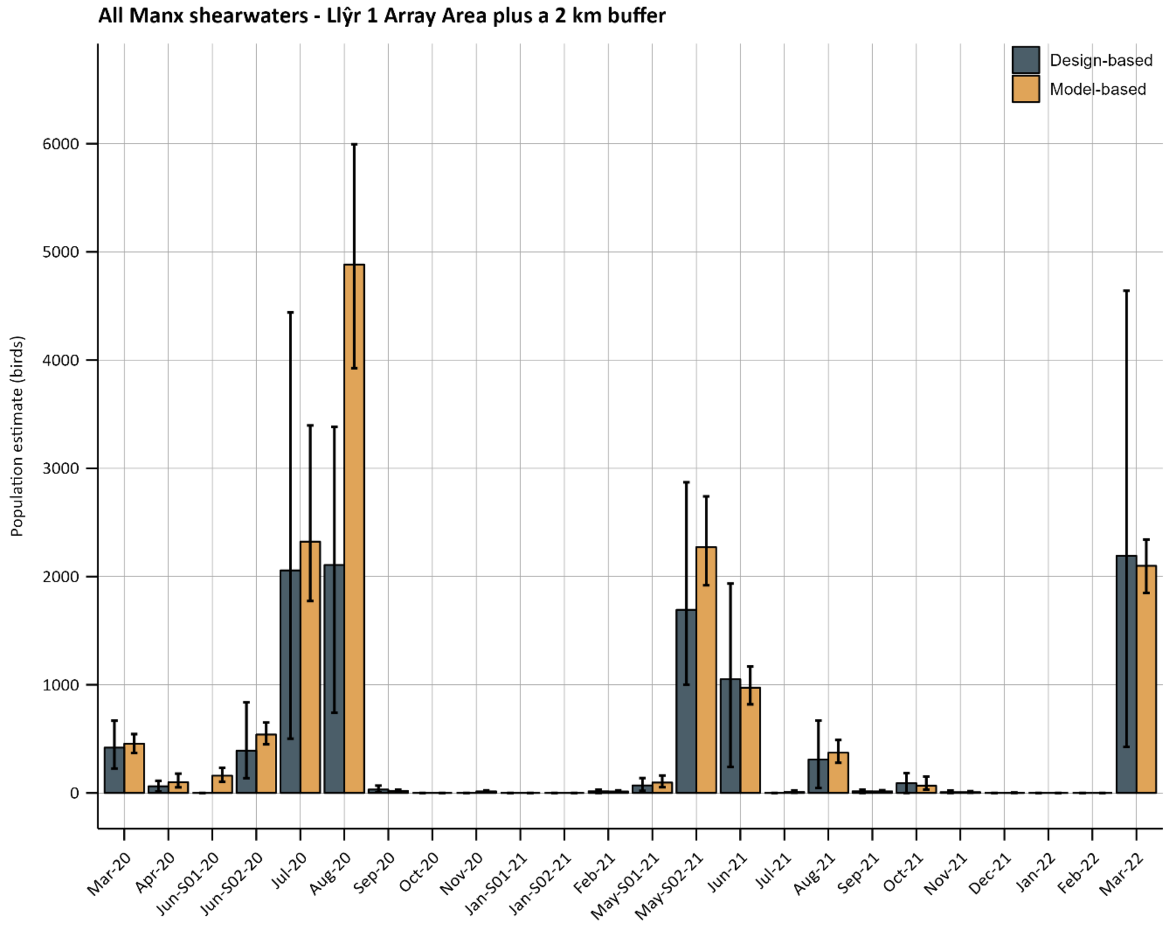

Figure 1-10 Monthly design-based and model-based population estimates of all Manx shearwaters (flying and sitting) within the Llŷr 1 Array Area plus a 2 km buffer between March 2020 and March 2022. Associated confidence intervals (design-based) and credible intervals (model-based) are represented by error bars

Figure 1-11. Distribution map of all recorded Manx shearwater (flying and sitting) within the Llŷr Marine Ornithology Survey Area in August 2020. Note that due to red line boundary refinement only Llŷr 1 will be progressed to Application.

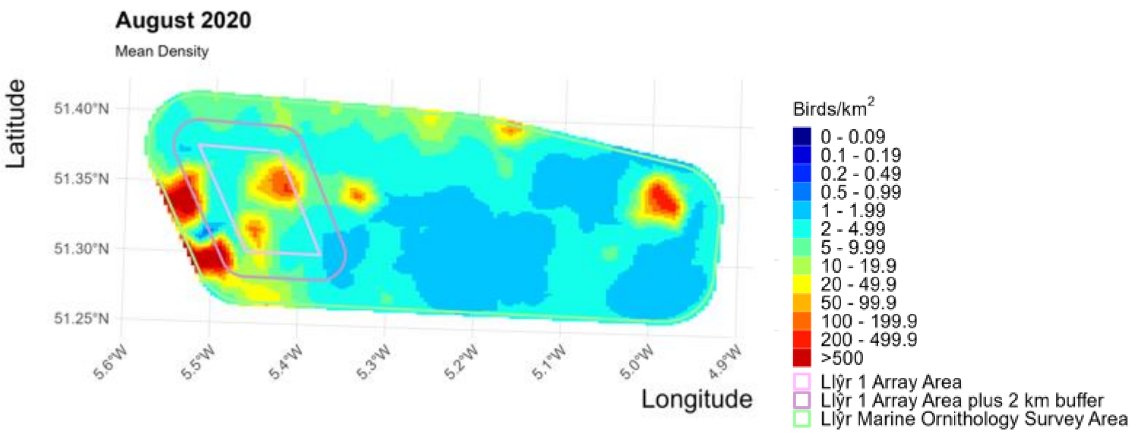

Figure 1-12. Mean model-based density surface for all Manx shearwaters (flying and sitting) in the Llŷr Marine Ornithology Survey Area in August 2020

Across the Llŷr 1 Array Area plus a 2 km buffer, the maximum design-based and model-based MSPs were recorded in the breeding season (**Table 1-4**). MSPs were similar between both approaches for the autumn migration season, but considerably different for the breeding season. Overall, confidence / credible intervals around the MSPs were comparable between both approaches for the autumn migration season but much more variable for the other two seasons.

Table 1-4. Comparison of design-based and model-based mean seasonal peak population estimates of all Manx shearwaters (flying and sitting) in each season within the Llŷr 1 Array Area plus 2 km buffer between March 2020 and March 2022

Manx shearwater	Population estimate (number) (design / model)	Lower 95% confidence / credible limit (number) (design / model)	Upper 95% confidence / credible limit (number) (design / model)
Llŷr 1 Array Area plus a 2 km buffer			
Breeding season	1,900 / 3,577	737 / 2,746	3,070 / 4,408
Autumn migration	61 / 44	7 / 7	134 / 87
Spring migration	1,306 / 1,278	148 / 1,085	2,945 / 1,470

1.7. Gannet

The maximum design-based and model-based density estimates of flying gannets in the Llŷr 1 Array Area were recorded in the spring migration period and the breeding season, with 1.09 birds/km^2 (0.83 SD; February 2021) and 1.72 birds/km^2 (0.65 SD; August 2021), respectively (**Figure 1-13**). Overall, model-based and design-based estimates were quite varied throughout the survey period, with particularly large confidence limits surrounding the design-based estimates in some months. The largest discrepancy between the design and model-based estimates occurred in April 2020 and August 2021, where modelling predicted higher densities. This is likely due to relatively high densities occurring elsewhere outside of the Llŷr 1 Array Area, as the model is informed by the spatial locations of birds throughout the Llŷr Marine Ornithology Survey Area (**Figure 1-14 and Figure 1-15**). The model is predicting densities in areas which have not been sampled (i.e., between the strips), so the areas next to strips with high densities of birds are also likely to have high density predictions.

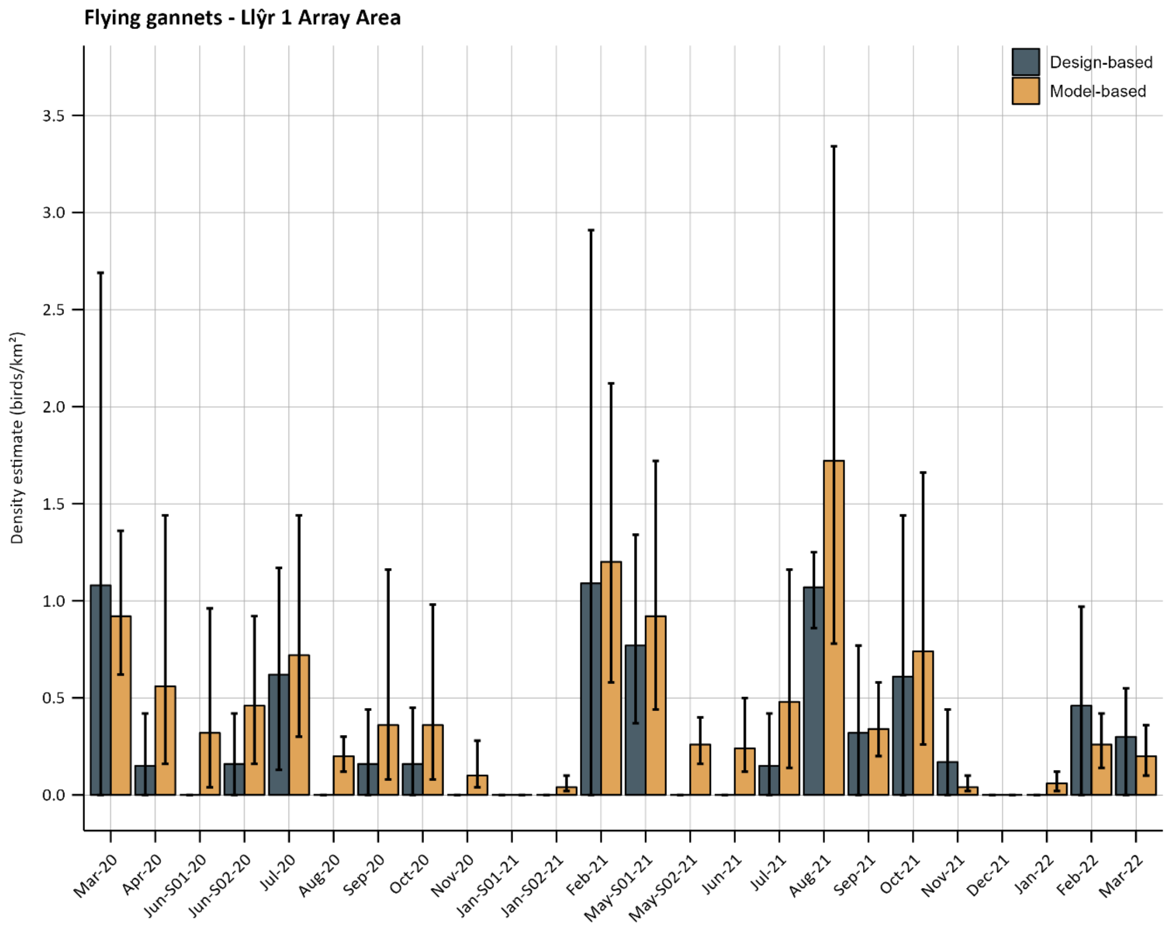

Figure 1-13. Monthly design-based and model-based density estimates of flying gannets within the Llŷr 1 Array Area between March 2020 and March 2022. Associated confidence intervals (design-based) and credible intervals (model-based) are represented by error bars

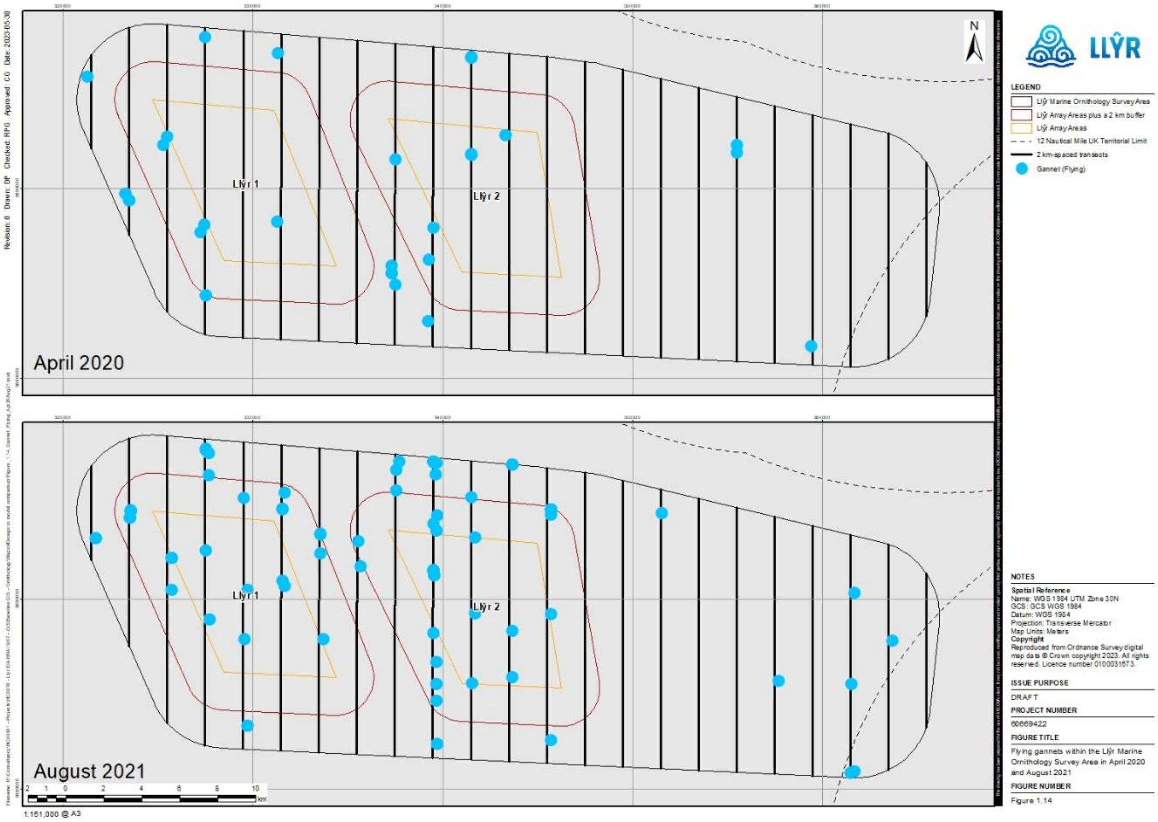

Figure 1-14. Distribution map of recorded flying gannets within the Llŷr Marine Ornithology Survey Area in April 2020 and August 2021. Note that due to red line boundary refinement only Llŷr 1 will be progressed to Application.

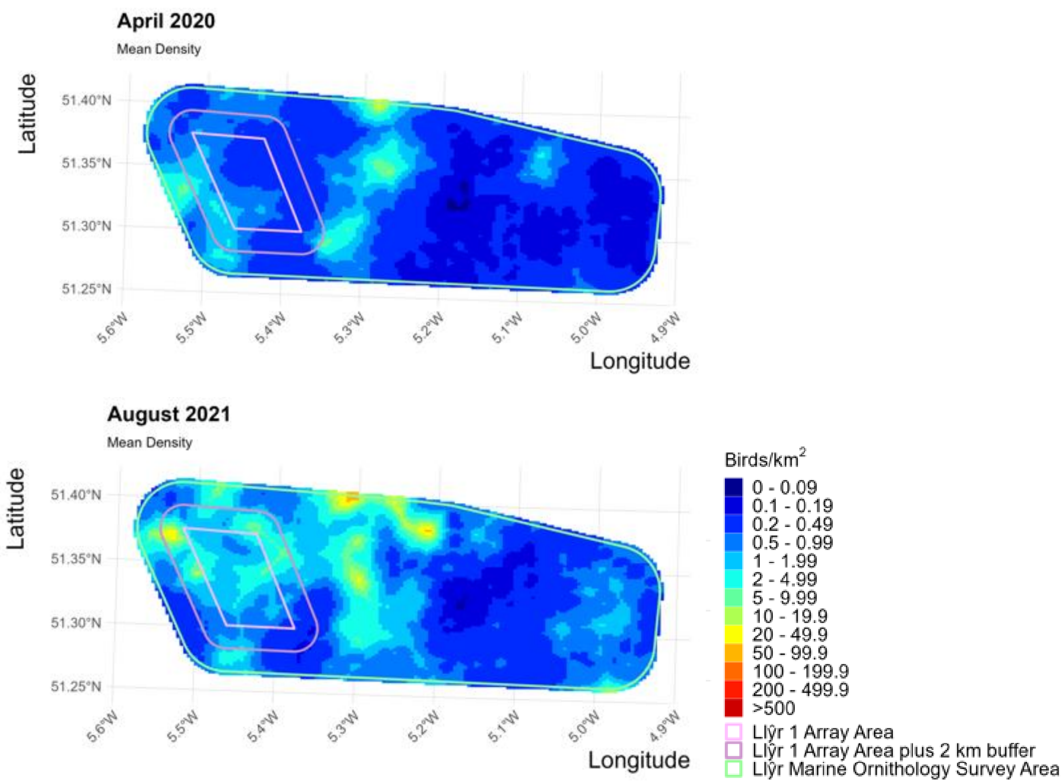

Figure 1-15. Mean model-based density surface for flying gannets in the Llŷr Marine Ornithology Survey Area in April 2020 and August 2021

The maximum design-based and model-based population estimates for all gannets (flying and sitting) in the Llŷr 1 Array Area plus a 2 km buffer were recorded during the autumn migration with 871 birds (95% CI 409 – 1,323; October 2021) and 1,034 birds (95% CI 858 – 1,288; October 2021), respectively (**Figure 1-16**). Overall, model-based and design-based estimates were relatively consistent throughout the survey period, with model-based estimates being slightly higher. The largest discrepancy between the design and model-based estimates occurred in November 2020, where the design-based method produced an estimate of 0 birds compared to 323 birds through modelling. Whilst no gannets were recorded within the Llŷr 1 Array Area plus a 2km buffer in this month, the model is informed by the spatial locations of birds throughout the Llŷr Marine Ornithology Survey Area, with birds recorded just outside of the perimeter, particularly to the south (**Figure 1-17 and Figure 1-18**).

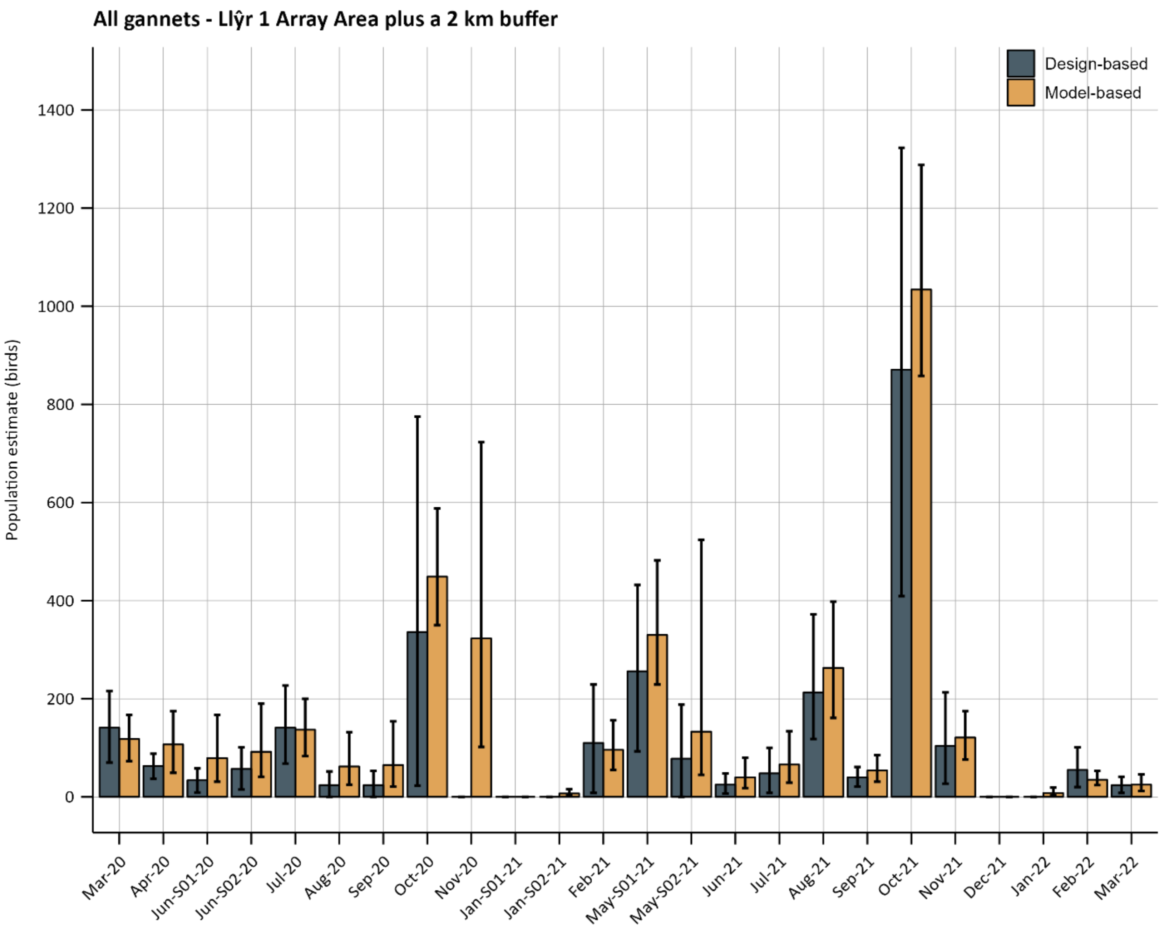

Figure 1-16. Monthly design-based and model-based population estimates of all gannets (flying and sitting) within the Llŷr 1 Array Area plus a 2 km buffer between March 2020 and March 2022. Associated confidence intervals (design-based) and credible intervals (model-based) are represented by error bars

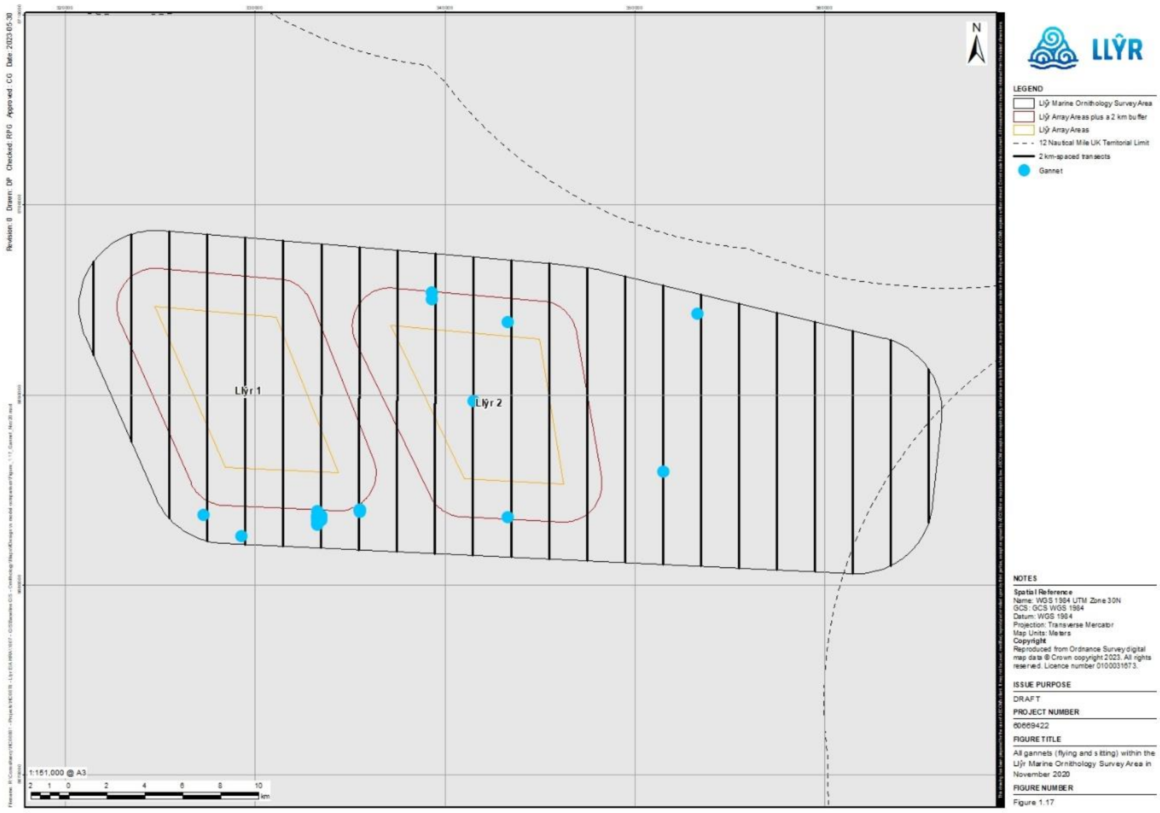

Figure 1-17. Distribution map of all recorded gannets (flying and sitting) within the Llŷr Marine Ornithology Survey Area in November 2020. Note that due to red line boundary refinement only Llŷr 1 will be progressed to Application.

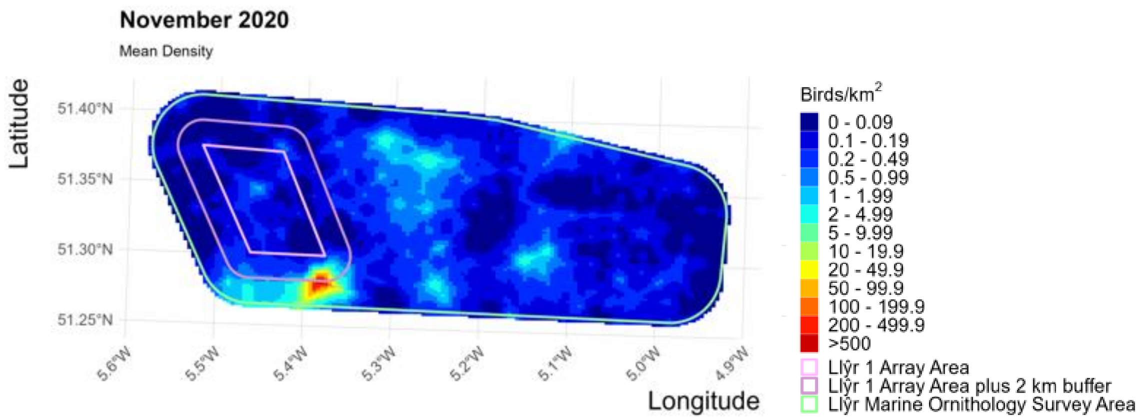

Figure 1-18. Mean model-based density surface for all gannets (flying and sitting) in the Llŷr Marine Ornithology Survey Area in November 2020

Across the Llŷr 1 Array Area plus a 2 km buffer, the maximum design-based and model-based MSPs were recorded in the autumn migration season (**Table 1-5**). MSPs were similar between both approaches in all seasons. Overall confidence / credible intervals around the MSPs were comparable between both approaches for all seasons, albeit narrower confidence / credible intervals tended to be present for model-based estimates.

Table 1-5. Comparison of design-based and model-based mean seasonal peak population estimates of all gannets (flying and sitting) in each season within the Llŷr 1 Array Area plus 2 km buffer between March 2020 and March 2022

Gannet	Population estimate (number) (design / model)	Lower 95% confidence / credible limit (number) (design/ model)	Upper 95% confidence / credible limit (number) (design / model)
Llŷr 1 Array Area plus a 2 km buffer			
Breeding season	198 / 234	68 / 134	330 / 333
Autumn migration	604 / 742	186 / 563	1,032 / 920
Spring migration	82 / 66	11 / 26	171 / 105

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FLOVENTIS ENERGY

LLŶR FLOATING OFFSHORE WIND PROJECT

LLŶR

MARINE MAMMALS

Comparison of Model (inlabru) and Design-Based Estimates from Digital Aerial Survey Work and

Advice on Density Estimates to Use in Noise Assessment

Prepared by: HiDef Aerial Surveying Ltd

June 2023

Acronyms and Abbreviations

Acronym or Abbreviation	Definition	Acronym or Abbreviation	Definition
adbe	Absolute design-based estimate		
ambe	Absolute model-based estimate		
DAS	Digital video aerial survey		
rmbe	Relative model-based estimate		
rdbe	Relative design-based estimate		

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1. Introduction

This technical report has been prepared to provide NRW (A) and JNCC with a summary of available density estimates (DAS/literature) that could be used in impact assessment for the proposed project Llŷr. This report responds to written advice from NRW(A) received 17/02/2023 and discussed at the meeting held on 09/05/2023. This summary report sets out the choice of densities for key species (grey seal, harbour porpoise, common dolphin, bottlenose dolphin and minke whale) together with the suggested density estimate to take forward to assessment and rationale.

Within this report, we also set out the site-based density estimates based on both the model-based (inalbru) and design-based for comparison. These are presented for harbour porpoise and common dolphin only because other species were recorded in low numbers and so are not suitable for site-specific modelled density estimation. **Figure 1-1** details Llŷr 1 site plus a 4 km buffer, and the megafauna survey area with transect lines overlain, together with the Erebus site for context.

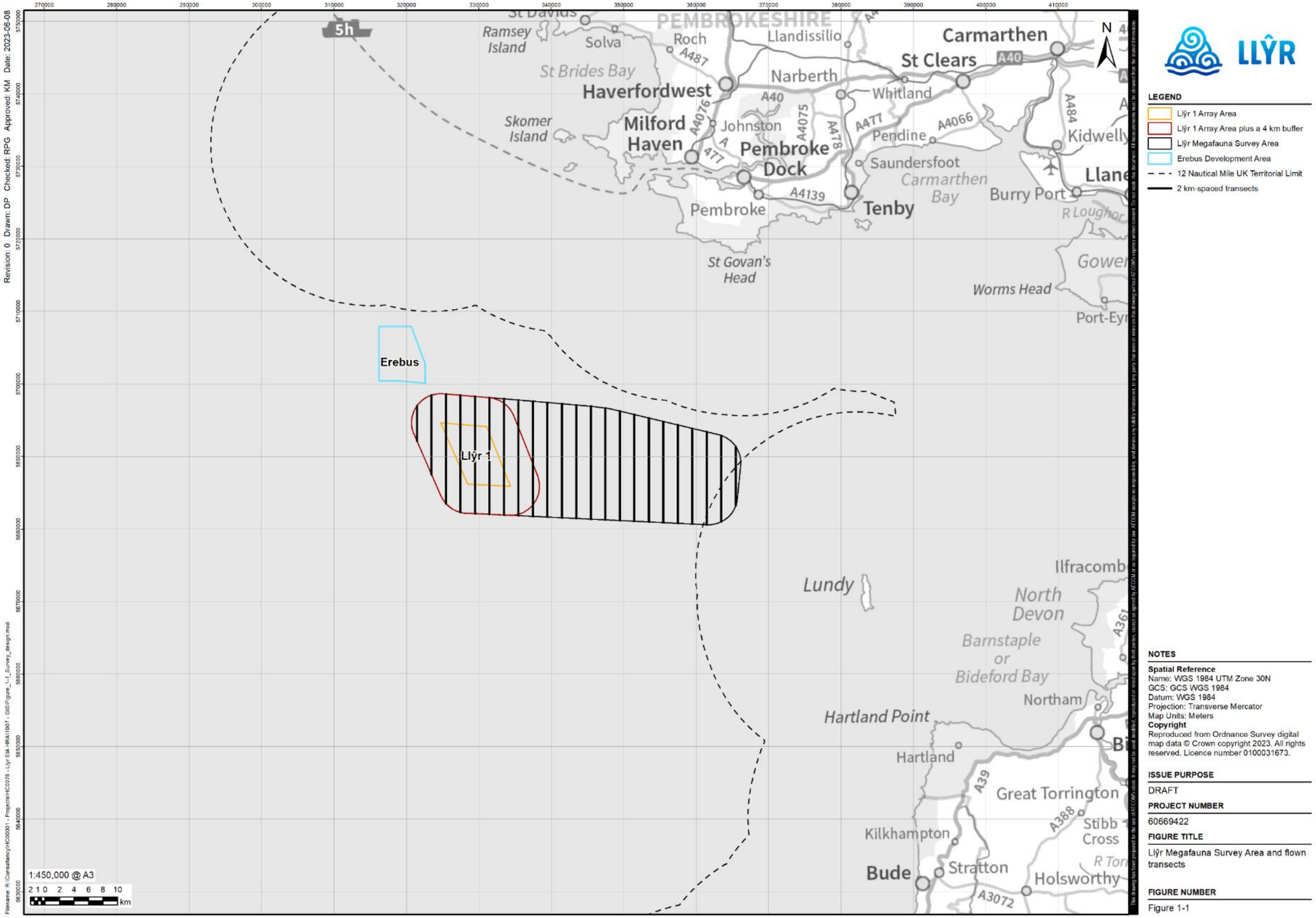

Figure 1-1 Llŷr 1, plus a 4 km buffer and Megafauna Survey Area overlain with flown transects

2. Digital Aerial Surveys (DAS) Model (Inlabru) And Design-Based Estimates

Marine mammal density and abundance estimates were calculated using both model-based (inlabru) and design-based methods, as set out and described in HiDef's paper 'Llŷr survey data analysis: design and model-based analysis methods' (16th March 2023). As agreed with NRW (A) and JNCC, analysis of the survey data has been undertaken by HiDef (supported by DMP Stats) only for harbour porpoise and common dolphin as the only two species recorded in sufficient numbers during the digital aerial survey programme to allow for robust and meaningful analysis.

Data across the full Llŷr Megafauna Survey Area was modelled using inlabru (method as described in HiDef's paper of 16th March 2023), with predictions then made for this full area, as well as the smaller Llŷr 1 Array Area plus 4 km buffer. Annual and two-year mean densities were calculated, alongside mean seasonal estimates for summer (May - October) and winter (November-April). All estimates were corrected for availability bias and unidentified animals (which were assigned to the relevant species using relative abundance ratios of the individual species within the wider category).

Harbour porpoise model-based absolute density estimates were higher during the summer and in the Year 1 compared to winter and Year 2, in both the Llŷr Megafauna Survey Area and the Llŷr 1 Array Area plus a 4 km buffer. The average model-based absolute densities across both years of survey equated 0.14 animals/km^2 (95% CI 0.02 – 0.54) and 0.14 animals/km^2 (95% CI 0.01 – 0.55) in each area, respectively (**Table 2-1** and **Table 2-2**).

Harbour porpoise design-based absolute density estimates were relatively similar between the summer and the winter, but greater in Year 1 compared to the Year 2 of survey in both the Llŷr Megafauna Survey Area and the Llŷr 1 Array Area plus a 4 km buffer. The average design-based densities across both years of survey equated 0.20 animals/km^2 (95% CI 0.14 – 0.26) and 0.17 animals/km^2 (95% CI 0.09 – 0.25) in each area, respectively (**Table 2-3** and **Table 2-4**).

Common dolphin model-based absolute density estimates were higher during the summer and in the Year 1 compared to winter and Year 2, in both the Llŷr Megafauna Survey Area and the Llŷr 1 Array Area plus a 4 km buffer. The average model-based absolute densities across both years of survey equated 15.97 animals/km^2 (95% CI 9.65 – 25.62) and 13.75 animals/km^2 (95% CI 8.40 – 22.11) in each area, respectively (**Table 2-5** and **Table 2-6**).

Common dolphin design-based absolute density estimates were higher during the summer and in the Year 1 compared to winter and Year 2, in both the Llŷr Megafauna Survey Area and the Llŷr 1 Array Area plus a 4 km buffer. The average design-based absolute densities across both years of survey equated 17.41 animals/km^2 (95% CI 12.01 – 22.81) and 15.81 animals/km^2 (95% CI 4.29 – 27.33) in each area, respectively (**Table 2-7** and **Table 2-8**).

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2.1. Harbour Porpoise

2.1.1. DAS Model-Based Estimates (Inlabru)

Table 2-1. Absolute model-based density and abundance estimates of harbour porpoise recorded in the Llŷr 1 Array Areas plus a 4 km buffer between March 2020 and March 2022 (where n = number, LCL = lower 95% credible limit, UCL = Upper 95% credible limit, SD = Standard Deviation of the Population, CV = Coefficient of Variation)

Survey date	Density (n/km²)	LCL (n/km²)	UCL (n/km²)	Population (n)	LCL (n)	UCL (n)	SD (n)	%CV
Total average	0.14	0.01	0.55	44.32	23.34	97.23	15.70	35.43
Summer average	0.15	0.09	0.24	32.50	19.71	48.48	7.46	22.96
Winter average	0.20	0.11	0.32	43.74	23.90	72.55	12.72	29.09
Average Year 1 (1 – 12)	0.30	0.22	0.43	67.55	48.32	96.23	12.02	17.80
Average Year 2 (13 – 24)	0.03	0.00	0.17	13.32	4.95	33.17	8.63	64.76

Table 2-2. Absolute model-based density and abundance estimates of harbour porpoise recorded in the Llŷr Megafauna Survey Area between March 2020 and March 2022 (where n = number, LCL = lower 95% credible limit, UCL = Upper 95% credible limit, SD = Standard Deviation of the Population, CV = Coefficient of Variation)

Survey date	Density (n/km²)	LCL (n/km²)	UCL (n/km²)	Population (n)	LCL (n)	UCL (n)	SD (n)	%CV
Total average	0.14	0.02	0.54	145.18	103.30	225.58	28.85	19.87
Summer average	0.16	0.10	0.25	105.28	71.37	159.50	21.27	20.20
Winter average	0.18	0.11	0.27	116.17	68.61	172.90	33.55	28.88
Average Year 1 (1 – 12)	0.31	0.23	0.42	199.35	147.12	269.36	32.06	16.08
Average Year 2 (13 – 24)	0.05	0.00	0.25	53.48	28.75	90.02	20.22	37.81

2.1.2. DAS Design-Based Estimates

Table 2-3. Absolute design-based density and abundance estimates of harbour porpoise recorded in the Llŷr 1 Array Areas plus a 4 km buffer between March 2020 and March 2022 (where n = number, LCL = lower 95% confidence limit, UCL = Upper 95% confidence limit, SD = Standard Deviation of the Population, CV = Coefficient of Variation)

Survey date	Density (n/km²)	LCL (n/km²)	UCL (n/km²)	Population (n)	LCL (n)	UCL (n)	SD (n)	%CV
25 Mar 2020	0.19	0.00	0.57	42	0	127	40	95.1
14 Apr 2020	0.16	0.00	0.48	36	0	106	33	92.06
08 Jun 2020	1.10	0.39	1.97	243	87	436	94	38.78
24 Jun 2020	0.41	0.00	0.98	91	0	217	58	63.19
21 Jul 2020	0.00	0.00	0.00	0	0	0	0	0
31 Aug 2020	0.00	0.00	0.00	0	0	0	0	0
12 Sep 2020	0.00	0.00	0.00	0	0	0	0	0
22 Oct 2020	0.24	0.00	0.74	54	0	165	51	94.12
26 Nov 2020	1.33	0.24	2.76	295	53	610	149	50.33
10 Jan 2021	0.00	0.00	0.00	0	0	0	0	0
25 Jan 2021	0.00	0.00	0.00	0	0	0	0	0
22 Feb 2021	0.27	0.00	0.79	60	0	175	54	88.95
14 May 2021	0.18	0.00	0.55	41	0	122	38	91.14
27 May 2021	0.00	0.00	0.00	0	0	0	0	0
15 Jun 2021	0.00	0.00	0.00	0	0	0	0	0
14 Jul 2021	0.00	0.00	0.00	0	0	0	0	0
16 Aug 2021	0.00	0.00	0.00	0	0	0	0	0
01 Sep 2021	0.26	0.00	0.74	58	0	163	50	86.77
22 Oct 2021	0.00	0.00	0.00	0	0	0	0	0
20 Nov 2021	0.00	0.00	0.00	0	0	0	0	0
16 Dec 2021	0.00	0.00	0.00	0	0	0	0	0
05 Jan 2022	0.00	0.00	0.00	0	0	0	0	0
26 Feb 2022	0.00	0.00	0.00	0	0	0	0	0
20 Mar 2022	0.00	0.00	0.00	0	0	0	0	0

Table 2-4. Absolute design-based density and abundance estimates of harbour porpoise recorded in the Llŷr Megafauna Survey Area between March 2020 and March 2022 (where n = number, LCL = lower 95% confidence limit, UCL = Upper 95% confidence limit, SD = Standard Deviation of the Population, CV = Coefficient of Variation)

Survey date	Density (n/km²)	LCL (n/km²)	UCL (n/km²)	Population (n)	LCL (n)	UCL (n)	SD (n)	%CV
25 Mar 2020	0.27	0.06	0.53	174	42	336	78	44.63
14 Apr 2020	0.06	0.00	0.17	38	0	108	36	94.8
08 Jun 2020	1.27	0.65	2.07	813	416	1321	236	28.99
24 Jun 2020	0.55	0.18	1.00	353	114	639	140	39.7
21 Jul 2020	0.15	0.00	0.37	97	0	239	64	65.65
31 Aug 2020	0.00	0.00	0.00	0	0	0	0	0
12 Sep 2020	0.00	0.00	0.00	0	0	0	0	0
22 Oct 2020	0.34	0.00	0.77	220	0	490	124	56
26 Nov 2020	0.63	0.17	1.26	405	112	803	188	46.27
10 Jan 2021	0.00	0.00	0.00	0	0	0	0	0
25 Jan 2021	0.22	0.00	0.59	141	0	375	105	74.1
22 Feb 2021	0.38	0.09	0.73	240	60	467	104	43.33
14 May 2021	0.13	0.00	0.32	83	0	204	56	67.46
27 May 2021	0.19	0.00	0.51	122	0	324	89	72.59
15 Jun 2021	0.00	0.00	0.00	0	0	0	0	0
14 Jul 2021	0.00	0.00	0.00	0	0	0	0	0
16 Aug 2021	0.00	0.00	0.00	0	0	0	0	0
01 Sep 2021	0.08	0.00	0.26	53	0	167	54	101.78
22 Oct 2021	0.00	0.00	0.00	0	0	0	0	0
20 Nov 2021	0.09	0.00	0.27	58	0	173	56	97.53
16 Dec 2021	0.09	0.00	0.33	56	0	211	54	95.42
05 Jan 2022	0.00	0.00	0.00	0	0	0	0	0
26 Feb 2022	0.28	0.00	0.83	180	0	529	172	95.93
20 Mar 2022	0.11	0.01	0.25	74	8	163	40	54.08

2.2. Common Dolphin

2.2.1. DAS Model-Based Estimates (Inlabru)

Table 2-5. Absolute model-based density and abundance estimates of common dolphins recorded in the Llŷr 1 Array Areas plus a 4 km buffer between March 2020 and March 2022 (where n = number, LCL = lower 95% credible limit, UCL = Upper 95% credible limit, SD = Standard Deviation of the Population, CV = Coefficient of Variation)

Survey date	Density (n/km²)	LCL (n/km²)	UCL (n/km²)	Population (n)	LCL (n)	UCL (n)	SD (n)	%CV
Total average	13.75	8.40	22.11	3785.43	3220.56	4369.08	823.39	21.75
Summer average	19.93	13.54	29.98	5710.09	4975.68	6453.35	1272.09	22.28
Winter average	6.32	2.87	12.54	1719.56	1326.24	2159.73	709.25	41.25
Average Year 1 (1 – 12)	22.64	13.46	38.23	6455.76	5618.03	7402.99	1517.63	23.51
Average Year 2 (13 – 24)	3.92	1.34	10.00	1233.22	892.42	1628.98	587.40	47.63

Table 2-6. Absolute model-based density and abundance estimates of common dolphins recorded in the Llŷr Megafauna Survey Area between March 2020 and March 2022 (where n = number, LCL = lower 95% credible limit, UCL = Upper 95% credible limit, SD = Standard Deviation of the Population, CV = Coefficient of Variation)

Survey date	Density (n/km²)	LCL (n/km²)	UCL (n/km²)	Population (n)	LCL (n)	UCL (n)	SD (n)	%CV
Total average	15.97	9.65	25.62	11966.23	10910.56	13007.64	2770.16	23.15
Summer average	22.56	14.64	34.37	17401.90	16117.09	18692.01	4081.09	23.45
Winter average	7.66	3.93	14.11	6224.29	5411.21	7074.64	2251.04	36.17
Average Year 1 (1 – 12)	20.94	11.74	36.63	14813.06	14184.86	15078.03	4351.55	29.38
Average Year 2 (13 – 24)	9.96	4.65	20.32	8123.45	7188.59	9208.13	2796.80	34.43

2.2.2. DAS Design-Based Estimates

Table 2-7. Absolute design-based density and abundance estimates of common dolphins recorded in the Llŷr 1 Array Areas plus a 4 km buffer between March 2020 and March 2022 (where n = number, LCL = lower 95% confidence limit, UCL = Upper 95% confidence limit, SD = Standard Deviation of the Population, CV = Coefficient of Variation)

Survey date	Density (n/km²)	LCL (n/km²)	UCL (n/km²)	Population (n)	LCL (n)	UCL (n)	SD (n)	CV
25 Mar 2020	0.69	0.00	1.99	153	0	441	138	90.53
14 Apr 2020	0.00	0.00	0.00	0	0	0	0	0
08 Jun 2020	14.88	0.57	39.06	3292	126	8642	2445	74.26
24 Jun 2020	165.01	2.12	455.36	36508	469	100745	29851	81.77
21 Jul 2020	14.55	0.00	34.89	3220	0	7720	2013	62.52
31 Aug 2020	32.98	14.08	51.13	7297	3116	11313	2155	29.53
12 Sep 2020	3.86	0.00	9.27	855	0	2051	558	65.25
22 Oct 2020	39.47	2.38	101.96	8732	528	22558	6633	75.96
26 Nov 2020	21.82	5.31	44.38	4828	1176	9819	2373	49.16
10 Jan 2021	4.30	0.00	9.63	951	0	2131	586	61.63
25 Jan 2021	0.54	0.00	1.59	119	0	353	108	90.36
22 Feb 2021	31.28	10.29	57.84	6921	2277	12797	2650	38.29
14 May 2021	8.69	0.00	25.79	1922	0	5705	1717	89.35
27 May 2021	4.78	0.00	14.42	1059	0	3191	964	91.08
15 Jun 2021	6.81	0.99	15.03	1507	220	3325	845	56.04
14 Jul 2021	18.47	0.00	39.61	4087	0	8763	2286	55.93
16 Aug 2021	0.00	0.00	0.00	0	0	0	0	0
01 Sep 2021	0.00	0.00	0.00	0	0	0	0	0
22 Oct 2021	0.00	0.00	0.00	0	0	0	0	0
20 Nov 2021	11.10	2.52	21.56	2455	557	4771	1109	45.16
16 Dec 2021	0.00	0.00	0.00	0	0	0	0	0
05 Jan 2022	0.00	0.00	0.00	0	0	0	0	0
26 Feb 2022	0.00	0.00	0.00	0	0	0	0	0
20 Mar 2022	0.11	0.00	0.32	24	0	72	24	101.41

Table 2-8. Absolute design-based density and abundance estimates of common dolphins recorded in the Llŷr Megafauna Survey Area between March 2020 and March 2022 (where n = number, LCL = lower 95% confidence limit, UCL = Upper 95% confidence limit, SD = Standard Deviation of the Population, CV = Coefficient of Variation)

Survey date	Density (n/km²)	LCL (n/km²)	UCL (n/km²)	Population (n)	LCL (n)	UCL (n)	SD (n)	CV
25 Mar 2020	0.74	0.00	1.87	471	0	1197	331	70.18
14 Apr 2020	0.93	0.00	2.78	595	0	1777	567	95.26
08 Jun 2020	24.70	14.27	36.39	15776	9111	23240	3730	23.64
24 Jun 2020	115.48	41.29	237.97	73757	26370	151987	34212	46.38
21 Jul 2020	14.50	4.34	28.58	9260	2773	18252	4038	43.6
31 Aug 2020	30.47	17.21	45.02	19458	10990	28754	4523	23.24
12 Sep 2020	6.47	2.28	12.64	4134	1455	8071	1655	40.03
22 Oct 2020	16.29	2.41	39.79	10406	1539	25413	6910	66.41
26 Nov 2020	24.70	13.86	37.05	15778	8856	23666	3859	24.46
10 Jan 2021	2.89	0.00	6.47	1848	0	4135	1034	55.96
25 Jan 2021	34.25	3.57	92.49	21874	2283	59073	16638	76.06
22 Feb 2021	11.27	2.04	23.44	7200	1303	14970	3528	48.99
14 May 2021	3.02	0.00	9.10	1930	0	5815	1896	98.25
27 May 2021	35.33	11.97	66.04	22567	7648	42176	9191	40.73
15 Jun 2021	52.67	27.63	86.09	33642	17646	54984	9231	27.44
14 Jul 2021	18.68	6.31	33.32	11930	4033	21280	4306	36.09
16 Aug 2021	0.55	0.00	1.46	355	0	935	256	72.11
01 Sep 2021	0.00	0.00	0.00	0	0	0	0	0
22 Oct 2021	0.39	0.00	1.15	253	0	735	243	96.42
20 Nov 2021	5.49	1.13	10.57	3509	725	6751	1549	44.13
16 Dec 2021	4.65	0.00	11.18	2971	0	7141	1812	60.99
05 Jan 2022	13.95	5.23	23.65	8910	3344	15107	3083	34.6
26 Feb 2022	0.00	0.00	0.00	0	0	0	0	0
20 Mar 2022	0.37	0.05	0.93	237	32	592	150	62.93

3. Comparison Of DAS Model (Inlabru) And Design-Based Estimates

3.1. Harbour Porpoise

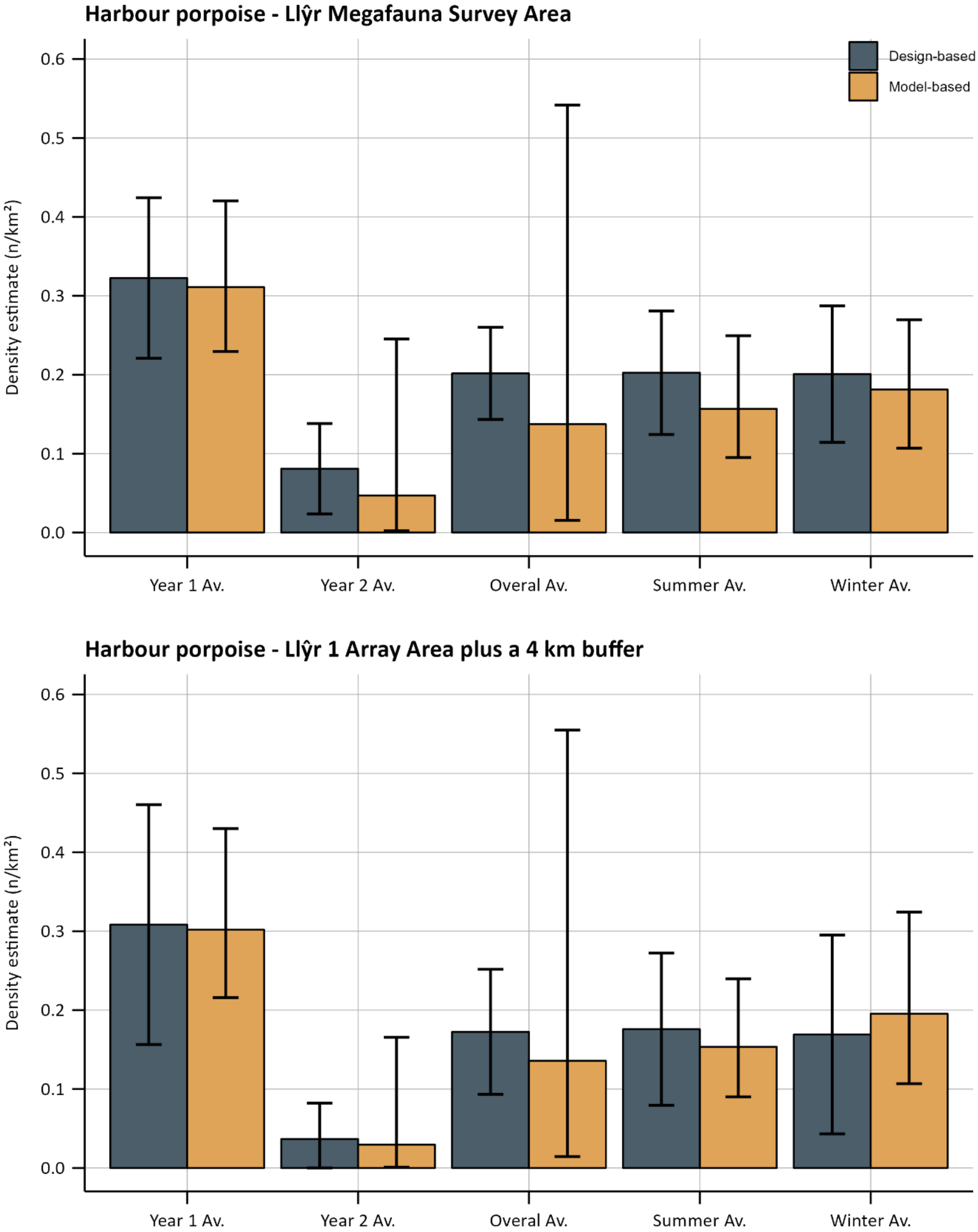


Figure 3-1. Year and seasonal average absolute design-based and model-based density estimates of harbour porpoise within the Llŷr Megafauna Survey Area and Llŷr 1 Array Area plus a 4 km buffer between March 2020 and March 2022. Associated confidence intervals (design-based) and credible intervals (model-based) are represented by error bars (Summer = May - October; Winter= November - April; Year 1= March 2020 – February 2021; Year 2= May S01 2021 – March 2022)

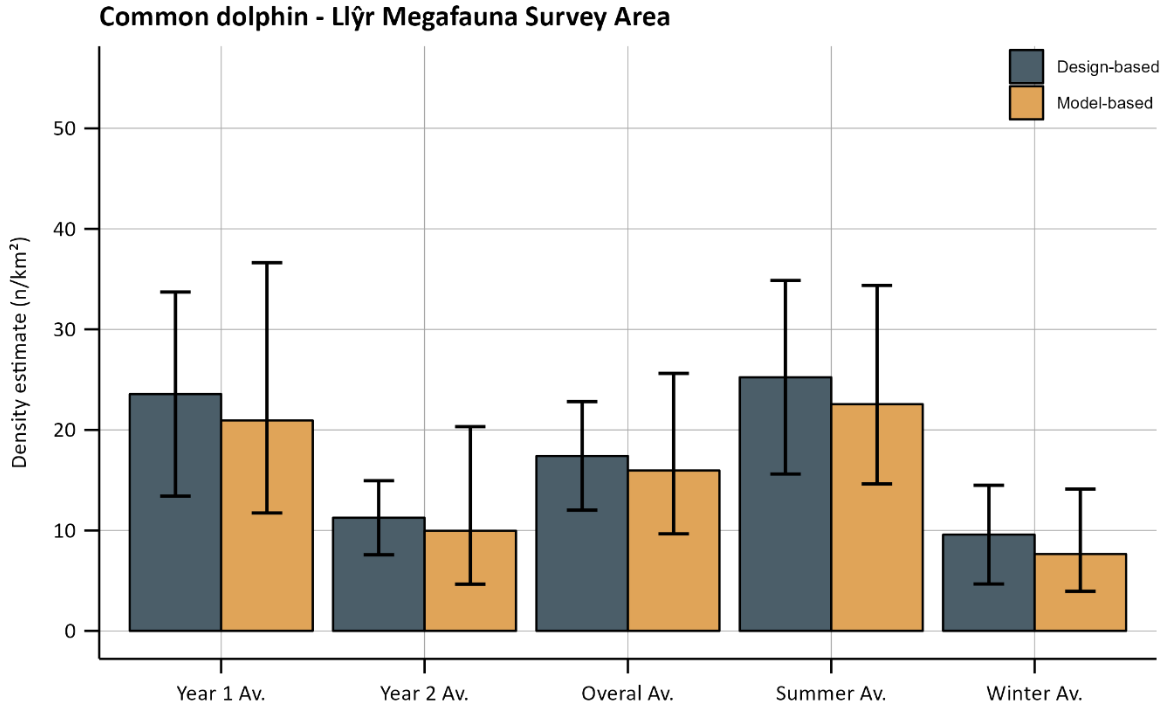
Table 3-1. Absolute design-based and model-based density and abundance estimates of harbour porpoise recorded in the Llŷr 1 Array Area plus a 4 km buffer between March 2020 and March 2022 (where n = number, LCL = lower 95% credible limit, UCL = Upper 95% credible limit, SD = Standard Deviation of the Population, CV = Coefficient of Variation)

Survey period	Density (n/km²)	LCL (n/km²)	UCL (n/km²)	Population (n)	LCL (n)	UCL (n)	SD (n)	%CV
Design-based estimates								
Total average	0.17	0.09	0.25	38	21	56	44	114.89
Summer average	0.18	0.08	0.27	39	18	61	38	96.96
Winter average	0.17	0.04	0.30	38	10	66	49	131.52
Average Year 1 (1 – 12)	0.31	0.16	0.46	68	35	102	60	87.09
Average Year 2 (13 – 24)	0.04	0.00	0.08	8	0	19	18	219.75
Model-based estimates								
Total average	0.14	0.01	0.55	44.32	23.34	97.23	15.70	35.43
Summer average	0.15	0.09	0.24	32.50	19.71	48.48	7.46	22.96
Winter average	0.20	0.11	0.32	43.74	23.90	72.55	12.72	29.09
Average Year 1 (1 – 12)	0.30	0.22	0.43	67.55	48.32	96.23	12.02	17.80
Average Year 2 (13 – 24)	0.03	0.00	0.17	13.32	4.95	33.17	8.63	64.76

Table 3-2. Absolute design-based and model-based density and abundance estimates of harbour porpoise recorded in the Llŷr Megafauna Survey Area between March 2020 and March 2022 (where n = number, LCL = lower 95% credible limit, UCL = Upper 95% credible limit, SD = Standard Deviation of the Population, CV = Coefficient of Variation)

Survey period	Density (n/km²)	LCL (n/km²)	UCL (n/km²)	Population (n)	LCL (n)	UCL (n)	SD (n)	CV
Design-based estimates								
Total average	0.20	0.14	0.26	129	92	167	94	72.35
Summer average	0.20	0.12	0.28	130	80	180	89	68.36
Winter average	0.20	0.11	0.29	129	73	185	98	76.18
Average Year 1 (1 – 12)	0.32	0.22	0.42	207	142	272	115	55.73
Average Year 2 (13 – 24)	0.08	0.02	0.14	52	15	89	65	125.22
Model-based estimates								
Total average	0.14	0.02	0.54	145.18	103.30	225.58	28.85	19.87
Summer average	0.16	0.10	0.25	105.28	71.37	159.50	21.27	20.20
Winter average	0.18	0.11	0.27	116.17	68.61	172.90	33.55	28.88
Average Year 1 (1 – 12)	0.31	0.23	0.42	199.35	147.12	269.36	32.06	16.08
Average Year 2 (13 – 24)	0.05	0.00	0.25	53.48	28.75	90.02	20.22	37.81

3.2. Common Dolphin



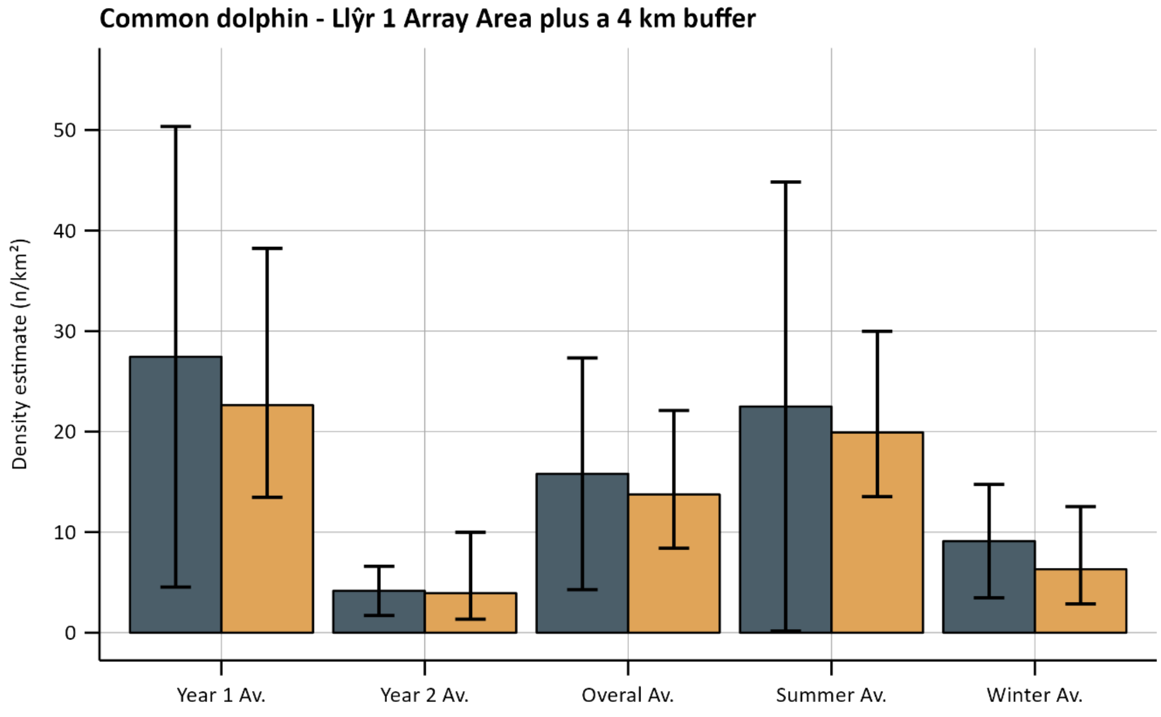


Figure 3-2. Year and seasonal average absolute design-based and model-based density estimates of common dolphins within the Llŷr Megafauna Survey Area and Llŷr 1 Array Area plus a 4 km buffer between March 2020 and March 2022. Associated confidence intervals (design-based) and credible intervals (model-based) are represented by error bars (Summer = April – September; Winter= October – March; Year 1= March 2020 – February 2021; Year 2= May S01 2021 – March 2022)

Table 3-3. Absolute design-based and model-based density and abundance estimates of common dolphins recorded in the Llŷr 1 Array Area plus a 4 km buffer between March 2020 and March 2022 (where n = number, LCL = lower 95% credible limit, UCL = Upper 95% credible limit, SD = Standard Deviation of the Population, CV = Coefficient of Variation)

Survey period	Density (n/km²)	LCL (n/km²)	UCL (n/km²)	Population (n)	LCL (n)	UCL (n)	SD (n)	%CV
Design-based estimates								
Total average	15.81	4.29	27.33	3497	948	6046	6371	182.18
Summer average	22.50	0.16	44.84	4979	36	9922	8736	175.47
Winter average	9.11	3.47	14.74	2015	769	3262	2203	109.33
Average Year 1 (1 – 12)	27.45	4.54	50.36	6073	1004	11142	8959	147.52
Average Year 2 (13 – 24)	4.16	1.71	6.62	921	378	1464	959	104.16
Model-based estimates								
Total average	13.75	8.40	22.11	3785.43	3220.56	4369.08	823.39	21.75
Summer average	19.93	13.54	29.98	5710.09	4975.68	6453.35	1272.09	22.28
Winter average	6.32	2.87	12.54	1719.56	1326.24	2159.73	709.25	41.25
Average Year 1 (1 – 12)	22.64	13.46	38.23	6455.76	5618.03	7402.99	1517.63	23.51
Average Year 2 (13 – 24)	3.92	1.34	10.00	1233.22	892.42	1628.98	587.40	47.63

Table 3-4. Absolute design-based model-based density and abundance estimates of common dolphins recorded in the Llŷr Megafauna Survey Area between March 2020 and March 2022 (where n = number, LCL = lower 95% credible limit, UCL = Upper 95% credible limit, SD = Standard Deviation of the Population, CV = Coefficient of Variation)

Survey period	Density (n/km²)	LCL (n/km²)	UCL (n/km²)	Population (n)	LCL (n)	UCL (n)	SD (n)	CV
Design-based estimates								
Total average	17.41	12.01	22.81	11119	7669	14569	8623	77.55
Summer average	25.23	15.61	34.86	16117	9971	22263	10863	67.40
Winter average	9.58	4.68	14.49	6121	2987	9256	5540	90.51
Average Year 1 (1 – 12)	23.56	13.40	33.71	15046	8560	21533	11465	76.20
Average Year 2 (13 – 24)	11.26	7.58	14.94	7192	4841	9543	4155	57.77
Model-based estimates								
Total average	15.97	9.65	25.62	11966.23	10910.56	13007.64	2770.16	23.15
Summer average	22.56	14.64	34.37	17401.90	16117.09	18692.01	4081.09	23.45
Winter average	7.66	3.93	14.11	6224.29	5411.21	7074.64	2251.04	36.17
Average Year 1 (1 – 12)	20.94	11.74	36.63	14813.06	14184.86	15078.03	4351.55	29.38
Average Year 2 (13 – 24)	9.96	4.65	20.32	8123.45	7188.59	9208.13	2796.80	34.43

4. Density Estimates for Use In Noise Assessment

This section summarises the key density estimates available in the literature, together with site-specific survey data for each species. A summary table of the literature sources can be found in **Annex A**, and the list of densities recommended for use in the impact assessment is summarised in **Section 4.3**.

Several sources (Annex A) have assessed the occurrence of marine mammals in the vicinity of the Project, which provide a choice of potential estimates of density and abundance to be taken forward for use in a quantitative impact assessment. Data analysis methodology is varied between these sources, with no way to determine which estimates reflect 'true' densities. Comparison between estimates derived through different studies should be done with caution. However, as sample sizes are small for marine mammals, the consideration of all available estimates is useful for context.

4.1. Grey Seal

Available density and abundance estimates provide a range from 0.000 animals/km^2 to 0.011 animals/km^2 (**Table 4-1**). Estimates of density and abundance from the site-specific survey data may be under representative due to difficulties differentiating between harbour and grey seals at-sea. There were six seals unidentified to species level, in comparison to 11 identified grey seals in the Llŷr Megafauna Survey Area. It should also be noted that none of the available estimates from the site survey were corrected for animals diving at the time of the survey or hauled out.

The most recent source is the site-specific survey data collected by HiDef between 2020 and 2022, which indicate that grey seals may be present in the vicinity of the Project in relatively low densities. The estimates gave a maximum average relative (un-corrected) design-based density for the full survey period of 0.011 animals/km^2 in the Llŷr Megafauna Survey Area.

The density estimates obtained from the surveys are comparable to the at-sea grey seal density data in Carter *et al.* (2022). However, due to the difficulty in differentiating grey seals from harbour seals in digital aerial surveys, we propose to use density estimates obtained from Carter *et al.* (2022) as this provides the more appropriate data to support the impact assessment. Relative densities were transformed into absolute densities using the steps detailed in Carter *et al.,* 2022 supplementary data. The % at-sea values by cell were multiplied by the reference total UK population, then divided by 100. This gives the **at-sea** number of individuals. This is then divided by 25 (area of the cell) to obtain the absolute at-sea density.

Table 4-1. Summary of grey seal density estimates collected around Llŷr (greyed cells correspond to the densities recommended to be used for quantitative impact assessment)

Study or survey programme	Area: Name	Area: Size (km^2)	Time scale	Average density (n/km^2)
Llŷr Project, HiDef site-specific surveys	Llŷr 1 Array Area plus a 4 km buffer	223.77	Year 1 Mar 2020 – Feb 2021	0.007 (rdbe)
			Year 2 May 2021 – Mar 2022	0.006 (rdbe)
			All surveys Mar 2020 – Mar 2022	0.006 (rdbe)
	Llŷr Megafauna Survey Area	640.92	Year 1 Mar 2020 – Feb 2021	0.011 (rdbe)
			Year 2 May 2021 – Mar 2022	0.004 (rdbe)
			All surveys Mar 2020 – Mar 2022	0.008 (rdbe)
Erebus Project, HiDef site-specific surveys (Darias-O'Hara *et al.,* 2021)	Erebus survey area (development area plus a 4 km buffer)	200.11	All surveys Oct 2019 – Sep 2021	0.003 (relative)
Grey seal at-sea density estimates in UK waters (Carter *et al*., 2022)	Llŷr 1 Array Area plus a 4 km buffer	223.77	2005 - 2019	0.004 (at-sea)
	Llŷr Megafauna Survey Area	640.92	2005 - 2019	**0.011 (at-sea)**

4.2. Harbour Porpoise

Available sources have provided a range of estimates from 0.030 animals/km^2 to 1.064 animals/km^2 (**Table 4-2**). All estimates presented in this report for harbour porpoise have accounted for animals diving at the time of the survey, providing absolute estimates of density and abundance.

The most recent data are site-specific digital video aerial survey data collected by HiDef between 2020 and 2022, which indicate some seasonal variation in abundance with higher densities estimated in the summer compared to winter. The average model-based absolute densities for the whole survey period were estimated at 0.137 animals/km^2 in the Llŷr Megafauna Survey Area. Estimated densities from the site-specific surveys data are slightly higher but consistent with those presented in SCANS-III (Hammond *et al*., 2021), but smaller than all other estimates recorded around the Project area (**Table 4-2**).

Given that available estimates for harbour porpoise are in site-specific surveys are comparable to SCANS-III estimates, we propose to use the site-specific surveys for quantitative impact assessment.

Table 4-2. Summary of harbour porpoise density estimates collected around Llŷr (highlighted cells correspond to the densities recommended to be used for quantitative impact assessment)

Study or survey programme	Area		Time scale	Average density (n/km²)
	Name	Size (km²)		
Llŷr Project, HiDef site-specific surveys	Llŷr 1 Array Area plus a 4 km buffer	223.77	Year 1 Mar 2020 – Feb 2021	0.308 (adbe) 0.302 (ambe)
			Year 2 May 2021 – Mar 2022	0.037 (adbe) 0.030 (ambe)
			All surveys Mar 2020 – Mar 2022	0.173 (adbe) 0.136 (ambe)
	Llŷr Megafauna Survey Area	640.92	Year 1 Mar 2020 – Feb 2021	0.323 (adbe) 0.311 (ambe)
			Year 2 May 2021 – Mar 2022	0.081 (adbe) 0.047 (ambe)
			All surveys Mar 2020 – Mar 2022	0.202 (adbe) **0.137** (ambe)
Erebus Project, HiDef site-specific surveys (Darias-O'Hara *et al.,* 2021)	Erebus survey area (development area plus a 4 km buffer)	200.11	Year 1 Oct 2019 – Sep 2020	0.037 (relative) 0.200 (absolute)
			Year 2 Oct 2020 – Sep 2021	0.100 (relative) 0.590 (absolute)
			All surveys Oct 2019 – Sep 2021	0.070 (relative) 0.400 (absolute)
SCANS-III surveys (Hammond *et al.,* 2021)	Block D – Celtic and Irish Seas	48,590	Jun – Jul 2016	0.118 (absolute)
ObSERVE surveys (Rogan *et al.,* 2018)	Stratum 4 – Celtic Sea	n/a	Summer 2015	0.227 (adbe) 0.205 (ambe)
			Winter 2015	0.060 (adbe)
			Summer 2016	0.227 (adbe) 0.222 (ambe)
	Stratum 5 – Irish Sea	n/a	Summer 2015	0.696 (adbe) 0.675 (ambe)
			Winter 2015	0.867 (adbe)
			Summer 2016	1.064 (adbe) 0.942 (ambe)
			Winter 2016	0.924 (adbe)
JCP Phase III (Paxton *et al.,* 2016)	Atlantic Array	19,649	Winter 2010	0.433 (absolute)
			Spring 2010	0.361 (absolute)
			Summer 2010	0.438 (absolute)
			Autumn 2010	0.305 (absolute)
			Average 2010	0.384 (absolute)

4.3. Common Dolphin

Available sources have provided a range of estimates from 0.044 animals/km^2 to 27.45 animals/km^2 (**Table 4-3**). All estimates discussed in this report for common dolphin have accounted for animals diving at the time of the survey, providing absolute estimates of density and abundance.

The most recent data are the site-specific digital video aerial survey data collected by HiDef between 2020 and 2022, which indicate some seasonal variation in abundance with higher densities estimated in the summer compared to winter. The average model-based absolute densities for the whole survey period were estimated at 15.97 animals/km^2 Llŷr Megafauna Survey Area. Estimated densities from the site-specific surveys data are far greater than those presented in all other surveys conducted around the Project area (**Table 4-3**). Design based estimates (Table 2-7 and Table 2-8) show a much higher density estimate on 24 June 2020. This peak skews the average. Removing this peak brings the 'all survey' average down to 13.14 animals/km^2, and the median value to 6.47 animals/km^2. This is still much higher than SCANS-III and Erebus estimates, and therefore does not appear to be representative. We therefore recommend using the highest regional scale density estimate from SCANS-III block D of 0.374 animals/km^2. (See Figure 5-1 in Annex A: Literature Sources for SCANS-III and ObSERVE survey areas)

Table 4-3. Summary of common dolphin density estimates collected around Llŷr (highlighted cells correspond to the densities recommended to be used for quantitative impact assessment)

Study or survey programme	Area		Time scale	Average density (n/km^2)
	Name	Size (km^2)		
Llŷr Project, HiDef site-specific surveys	Llŷr 1 Array Area plus a 4 km buffer	223.77	Year 1 Mar 2020 – Feb 2021	27.45 (adbe) 22.64 (ambe*)
			Year 2 May 2021 – Mar 2022	4.16 (adbe) 3.92 (ambe)
			All surveys Mar 2020 – Mar 2022	15.81 (adbe) 13.75 (ambe)
	Llŷr Megafauna Survey Area	640.92	Year 1 Mar 2020 – Feb 2021	23.56 (adbe) 20.94 (ambe)
			Year 2 May 2021 – Mar 2022	11.26 (adbe) 9.96 (ambe)
			All surveys Mar 2020 – Mar 2022	17.41 (adbe) 15.97 (ambe)
Erebus Project, HiDef site-specific surveys (Darias-O'Hara *et al.,* 2021)	Erebus survey area (development area plus a 4 km buffer)	200.11	Year 1 Oct 2019 – Sep 2020	2.13 (relative) 2.26 (absolute)
			Year 2 Oct 2020 – Sep 2021	0.91(relative) 0.97 (absolute)
			All surveys Oct 2019 – Sep 2021	1.52 (relative) 1.61 (absolute)
SCANS-III surveys (Hammond *et al.,* 2021)	Block D – Celtic and Irish Seas	48,590	Jun – Jul 2016	**0.374** (absolute)
ObSERVE surveys (Rogan *et al.,* 2018)	Stratum 4 – Celtic Sea	n/a	Summer 2015	0.044 (adbe)
			Winter 2015	0.637 (adbe)

Study or survey programme	Area		Time scale	Average density (n/km²)
	Name	Size (km²)		
JCP Phase III (Paxton *et al.,* 2016)	Atlantic Array	19,649	Winter 2010	0.124 (absolute)
			Spring 2010	0.319 (absolute)
			Summer 2010	0.407 (absolute)
			Autumn 2010	1.686 (absolute)
			Average 2010	0.634 (absolute)

** ambe: absolute model-based estimates*

4.1. Bottlenose Dolphin

Available sources have provided a range of estimates from 0.000 animals/km² to 0.929 animals/km² (**Table 4-4**). It should be noted that estimates from the JCP phase III, SCANS-III and ObSERVE surveys (Paxton *et al*., 2016; Rogan *et al.,* 2018; Hammond *et al.,* 2021), provide absolute estimates, with correction for visibility bias at the time of the surveys.

The most recent data are site-specific survey data collected by HiDef at the Erebus Project between 2019 and 2021 which indicate bottlenose dolphins may be present in the vicinity of the Project in relatively low densities. The estimates gave an average relative (not corrected) density for the full survey period of 0.003 animals/km², with peak estimates recorded during the summer period (0.04 animals/km² [June 2020]). Estimated densities from the Erebus site-specific survey data are overall much lower than those presented in SCANS and ObSERVE (Rogan *et al*., 2018; Hammond *et al*., 2021).

Given the absence of estimates for bottlenose dolphins in the Llŷr site-specific surveys, and the low estimates at the Erebus project compared to SCANS-III and ObSERVE, the higher of the SCANS-III block estimates (Block D) should be used for quantitative impact assessment. This estimate of 0.061 animals/km² represents absolute abundance and is spatially relevant to the area of the offshore Project.

Table 4-4. Summary of bottlenose dolphin density estimates collected around Llŷr (highlighted cell corresponds to the density recommended to be used for quantitative impact assessment)

Study or survey programme	Area		Time scale	Average density (n/km²)
	Name	Size (km²)		
Erebus Project, HiDef site-specific surveys (Darias-O'Hara *et al.,* 2021)	Erebus survey area (development area plus a 4 km buffer)	200.11	Year 1 Oct 2019 – Sep 2020	0.007 (relative)
			Year 2 Oct 2020 – Sep 2021	0.000 (relative)
			All surveys Oct 2019 – Sep 2021	0.003 (relative)
SCANS-III surveys (Hammond *et al.,* 2021)	Block D – Celtic and Irish Seas	48,590	Jun – Jul 2016	**0.061** (absolute)

Study or survey programme	Area		Time scale	Average density (n/km²)
	Name	Size (km²)		
ObSERVE surveys (Rogan *et al.,* 2018)	Stratum 4 – Celtic Sea	n/a	Summer 2015	0.062 (adbe)
			Winter 2015	0.098 (adbe) 0.095(ambe)
			Summer 2016	0.088 (adbe) 0.155 (ambe)
			Winter 2016	0.929 (adbe) 0.914 (ambe)
	Stratum 5 – Irish Sea	n/a	Summer 2016	0.011 (ambe)
			Winter 2016	0.036 (adbe) 0.020 (ambe)
JCP Phase III (Paxton *et al.,* 2016)	Atlantic Array	19,649	Winter 2010	0.004 (absolute)
			Spring 2010	0.005 (absolute)
			Summer 2010	0.006 (absolute)
			Autumn 2010	0.002 (absolute)
			Average 2010	0.004 (absolute)

4.2. Minke Whale

Available sources have provided a range of estimates from 0.000 animals/km^2 to 0.045 animals/km^2 (**Table 4-5**). It should be noted that estimates from site-specific surveys provided relative design-based estimates (rdbe) with no correction for animals diving at the time of the survey, while estimates derived from the JCP phase III, SCANS-III and ObSERVE surveys (Paxton *et al*., 2016; Rogan *et al*., 2018; Hammond *et al*., 2021), provide absolute estimates of abundance.

The most recent data are site-specific surveys data collected by HiDef between 2020 and 2022 which indicate minke whales may be present in the vicinity of the Project in relatively low densities. The estimates gave an average relative design-based density for the full survey period of 0.004 animals/km^2, and 0.003 animals/km^2 in the Llŷr Array Area plus a 4 km buffer and the Llŷr Megafauna Survey Area respectively, with peak estimates recorded during the summer period (*e.g.,* 0.07 animals/km^2 [June 2020]). Estimated densities from the site-specific surveys data are overall lower than those presented in SCANS-III and ObSERVE (Rogan *et al*., 2018; Hammond *et al*., 2021), but noting that site-specific densities are not corrected for availability bias.

Given that available estimates for minke whales are lower and relative in site-specific surveys compared to SCANS-III and ObSERVE (absolute), the higher of the SCANS-III block estimates (block D overlapping with the Project) should be used for quantitative impact assessment. This estimate of 0.011 animals/km^2 represents absolute abundance and is spatially relevant to the area of the offshore Project.

Table 4-5. Summary of minke whale density estimates collected around Llŷr (highlighted cell corresponds to the density recommended to be used for quantitative impact assessment)

Study or survey programme	Area		Time scale	Average density (n/km^2)
	Name	Size (km^2)		
Llŷr Project, HiDef site-specific surveys	Llŷr 1 Array Area plus a 4 km buffer	223.77	Year 1 Mar 2020 – Feb 2021	0.006 (rdbe*)
			Year 2 May 2021 – Mar 2022	0.003 (rdbe)
			All surveys Mar 2020 – Mar 2022	0.004 (rdbe)
	Llŷr Megafauna Survey Area	640.92	Year 1 Mar 2020 – Feb 2021	0.003 (rdbe)
			Year 2 May 2021 – Mar 2022	0.002 (rdbe)
			All surveys Mar 2020 – Mar 2022	0.003 (rdbe)
Erebus Project, HiDef site-specific surveys (Darias-O'Hara *et al.,* 2021)	Erebus survey area (development area plus a 4 km buffer)	200.11	Year 1 Oct 2019 – Sep 2020	0.003 (relative)
			Year 2 Oct 2020 – Sep 2021	0.000 (relative)
			All surveys Oct 2019 – Sep 2021	0.002 (relative)
SCANS-III surveys (Hammond *et al.,* 2021)	Block D – Celtic and Irish Seas	48,590	Jun – Jul 2016	**0.011** (absolute)
ObSERVE surveys (Rogan *et al.,* 2018)	Stratum 4 – Celtic Sea	n/a	Summer 2015	0.013 (adbe**)
			Winter 2015	0.012 (adbe)
			Summer 2016	0.012 (adbe)
			Winter 2016	0.000 (adbe)
	Stratum 5 – Irish Sea	n/a	Summer 2015	0.045 (adbe)
			Winter 2015	0.000 (adbe)
			Summer 2016	0.016 (adbe)
			Winter 2016	0.000 (adbe)
JCP Phase III (Paxton *et al.,* 2016)	Atlantic Array	19,649	Winter 2010	0.002 (absolute)
			Spring 210	0.006 (absolute)
			Summer 2010	0.014 (absolute)
			Autumn 2010	0.003 (absolute)
			Average 2010	0.006 (absolute)

**rdbe: relative design-based estimates; **adbe: absolute design-based estimates*

4.3. Density Estimates Recommended for Impact Assessment

Currently available data on marine mammals and megafauna showed common dolphins, harbour porpoise, bottlenose dolphins, minke whales and grey seals occur in and around the Project, and should therefore, be considered within the quantitative impact assessment (**Table 4-6**).

Table 4-6. Summary of the density estimates recommended to bring forward for impact assessment

Species	Reference population (abundance)	Density (n/km^2) relevant to the Project	Density source
Grey seal	OSPAR III Region (62,358; SCOS, 2021; Carter *et al*., 2022)	0.011 (95% CI 0.003 – 0.035; Llŷr Megafauna Survey Area)*	At-sea densities (Carter *et al*., 2022)
Harbour porpoise	Celtic and Irish Sea (62,517; IAMMWG, 2022)	0.137 (95% CI 0.02 – 0.54; Llŷr Megafauna Survey Area)	Site-specific digital video aerial survey (absolute model-based overall average)
Common dolphin	Celtic and Greater North Seas (102,656; IAMMWG, 2022)	0.374 (0.413 CV ; outside the Llŷr Megafauna Survey Area)	SCANS-III survey block D (absolute design-based estimates; Hammond *et al*., 2021)
Bottlenose dolphin	Offshore Channel and SW England (10,947; IAMMWG, 2022)	0.061 (0.447 CV)	SCANS-III survey block D (absolute design-based estimates; Hammond *et al*., 2021)
Minke whale	Celtic and Greater North Seas (20,118; IAMMWG, 2022)	0.011 (0.755 CV)	SCANS-III survey block D (absolute design-based estimates; Hammond *et al*., 2021)

**mean density in the impacted area will vary depending on the grid cells that are extracted from the surface within it (Carter et al., 2022)*

5. Annex A: Literature Sources

Table 5-1 summarises the data sources being used to characterise the baseline environment for marine mammals and megafauna in relation to the Project.

Table 5-1. Data sources used to inform baseline characterisation of key marine mammal and megafauna species

Data source	Date	Type of data	Coverage
Project Erebus site-specific surveys (Darias-O'Hara *et al.*, 2021)	Oct 2019 – Sep 2021	Digital video aerial surveys	Project Erebus and 4 km buffer
Welsh Marine Atlas (Baines and Evans, 2012)	1990 – 2009	Aerial, vessel and land-based visual surveys	Welsh waters
SCANS-III (Hammond *et al.*, 2021)	Jul 2016	Aerial and vessel visual surveys	European Atlantic waters
ObSERVE (Rogan *et al.*, 2018)	Summer/ Winter 2015 and 2016	Visual aerial surveys	Offshore waters within and beyond Irish continental shelf
Sea Watch Foundation bottlenose dolphin surveys (Lohrengel *et al.*, 2018)	2014 – 2016	Vessel and photo-ID surveys	Cardigan Bay SAC and wider Cardigan Bay
JCP Phase III (Paxton *et al.*, 2016)	1994 – 2010	Aerial, vessel and land-based surveys	Northern European shelf
Harbour porpoise relatively high densities (Heinänen and Skov, 2015)	1994 – 2011	Vessel and aerial surveys	UK waters
MERP maps (Waggit *et al.*, 2019)	1980 – 2018	Aerial and vessel visual surveys	European Atlantic waters
SCOS seal haul-out surveys (SCOS, 2021)	2019	Haul-out surveys	UK coastline
Natural Resources Wales grey seal pup counts (Bull *et al*., 2017a; 2017b; Morgan *et al*., 2018)	1983 – 2015	Pup counts	Skomer Marine Conservation Zone (MCZ) and Pembrokeshire Marine SAC
Natural Resources Wales grey seal breeding census (Büche, 2021)	1983 -2021	Breeding census	Skomer MCZ
EIRPHOT (Langlay *et al*., 2018; 2020)	1992 – 2016	Adult grey seal photo ID	Welsh and Irish coastlines
Seal at-sea distribution (Vincent *et al*., 2017)	1999 – 2014	Telemetry data	East Atlantic and North Sea
Foraging habitat selection of grey and harbour seals (Huon *et al*., 2021)	2008 – 2014	Telemetry data	East Atlantic
Grey seal at-sea density (Russel *et al.* 2017	1988 - 2016	Telemetry data	UK, Irish and French waters
Grey seal at-sea density (Carter *et al.*, 2022)	1991 – 2019	Density surface based on telemetry and count data	UK and Irish waters
Wildfowl and Wetland Trust aerial surveys (WWT Consulting, 2009)	2001 – 2008	Visual aerial surveys	UK waters
Spatio-temporal distribution of basking shark populations in the northeast Atlantic (Witt *et al*., 2012)	1988 – 2008	Public sightings database, boat-based surveys	UK, Irish and northern French waters

Data source	Date	Type of data	Coverage
Spatio-temporal distribution of basking shark populations in the northeast Atlantic (Austin *et al*., 2019)	May – Jun 2000 to 2005	Public sightings database, boat-based surveys and habitat suitability maps	UK and Irish waters
	Jul – Aug 2002 to 2006	Public sightings database, boat-based surveys and habitat suitability maps	UK and Irish waters
Spatio-temporal distribution of basking shark populations in the northeast Atlantic (Doherty *et al*., 2017)	2012 – 2015	Telemetry data	Northeast Atlantic
Long-term insights into marine turtle sightings, strandings and captures around the UK and Ireland (TURTLE database) (Botterell *et al*., 2020)	1910 – 2021	Live and dead turtle sightings, strandings and captures	UK and Irish waters
British and Irish Marine Turtle Stranding and Sightings Annual Report (Penrose *et al*., 2022)	2011 – 2021	Live and dead turtle sightings, strandings and captures	UK and Irish waters
INTERREG Irish Sea leatherback turtle Project (Houghton *et al*., 2006a; 2006b)	2003 – 2005	Visual aerial surveys	Irish Sea
Leatherback turtles satellite-tagged in European waters (Doyle *et al*., 2008)	2005 – 2006	Telemetry data	Atlantic Ocean

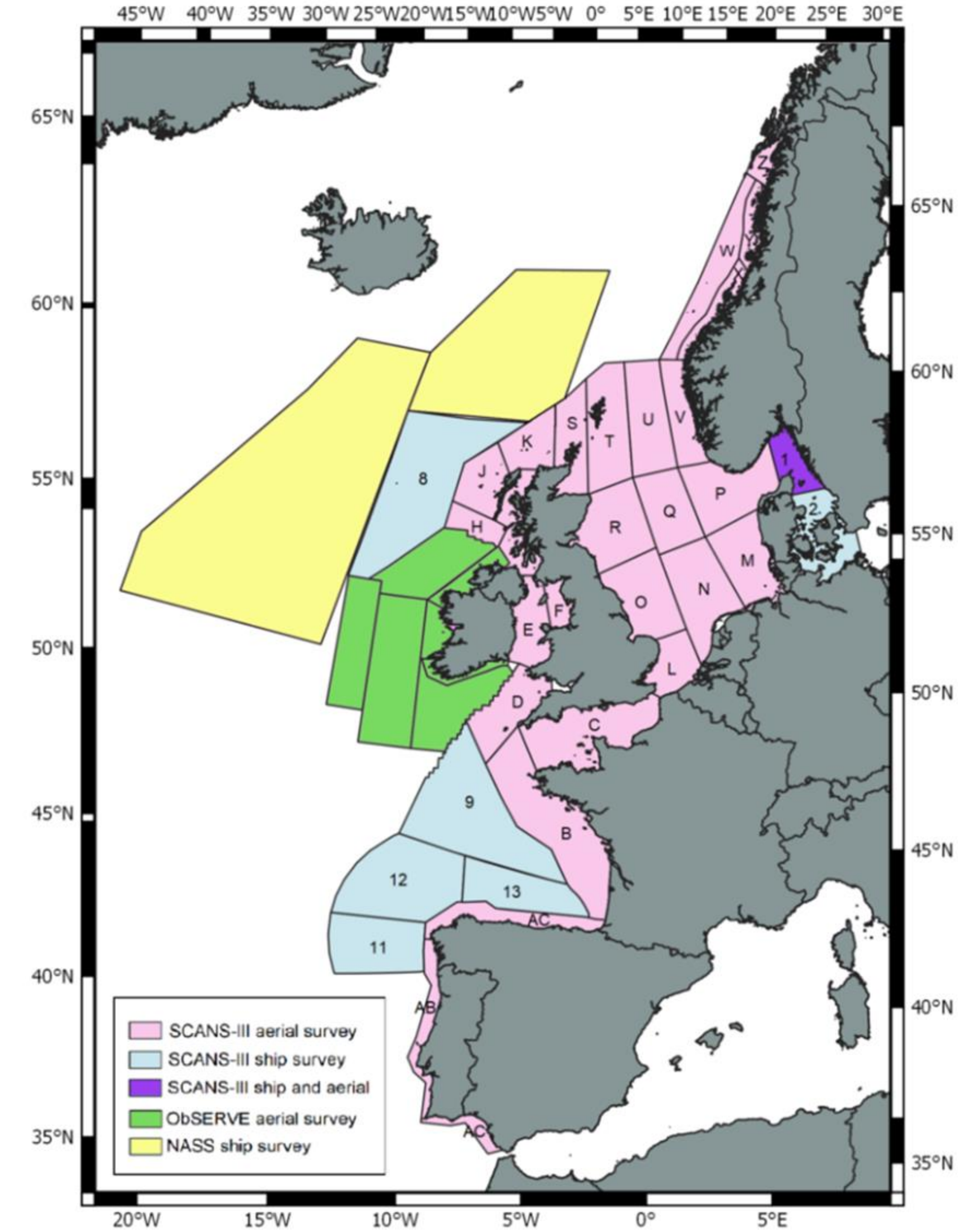


Figure 5-1 - SCANS III map of survey area July 2016, including area covered by ObSERVE in 2015-2016

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LLŶR FLOATING OFFSHORE WIND PROJECT

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LLŶR SURVEY DATA ANALYSIS

Survey Coverage Comparison (12.5% and 25.0%)

Prepared by: HiDef Aerial Surveying Ltd

March 2024

Acronyms and Abbreviations

Acronym or Abbreviation	Definition	Acronym or Abbreviation	Definition
CI	Credible Intervals		
CL	Credible Limits		
CV	Coefficient of Variation		
DAS	Digital Aerial Survey		
JNCC	Joint Nature Conservation Committee		
NRW (A)	National Resources Wales (Advisory)		
SD	Standard Deviation		

Glossary of Terms

Term	Definition
Credible Intervals	The credible interval is the central portion of the posterior distribution estimated by inlabru that contains 95% of the values, so the lower and upper limits are the minimum and maximum values from the credible interval.
Credible Limits	The upper and lower values that define the range of the 95% credible interval.
Coefficient of Variation	A standard measure that describes the dispersion of data points around the mean. The lower the CV the more precise the estimate. It is calculated as the standard deviation (SD) / mean.
Standard Deviation	The amount of variation or dispersion of a set of values. A low SD indicates that the bootstrap values tend to be close to the mean of the set.

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1. Introduction

This technical note presents a comparison of model-based density estimates for the Llŷr 1 Floating Offshore Wind Farm (the proposed Project) Array Area and additional 2 km buffer, comparing 12.5% and 25.0% survey coverage from digital aerial survey work (DAS). Model-based estimates were produced using the R package *inlabru* (Bach *et al.*, 2019).

This comparison has been undertaken to demonstrate that the DAS survey design for the proposed Project (12.5% survey coverage achieved using two cameras per transect) adequately characterises the baseline in relation to marine ornithological receptors. For these species, the project-specific density estimates clipped for the Array Area feed directly into quantified impact assessment (displacement / collision risk).

Baseline characterisation for marine mammals is more contextual and carried out at wider scale. A DAS-derived density estimate has only been taken forward for harbour porpoise in the quantitative assessment for the proposed Project (underwater noise). In this case, however, the data used is a pooled annual estimate for the entire DAS area, and does not relate specifically to the Array Area.

This short study focuses on seabirds and has been undertaken to fulfil the request from Natural Resource Wales Advisory (NRW (A))[4] to compare 12.5% and 25.0% survey coverage for a single survey (one month) and investigate whether an increase in coverage makes an appreciable difference to the precision of the density estimates thus obtained.

The March 2020 survey was selected for study as it includes the majority of key seabird species under assessment at the proposed Project Array Area and has a relatively high number of observations in comparison to other surveys. The Coefficients of Variation (CVs) are also relatively low in this survey (median = 21.3%), indicating that there are no serious abnormalities in the data which could affect the analysis.

The March 2020 data includes sufficient observations of the following key species to be able to address them in this study.

Displacement species:

- northern gannet (*Morus bassanus*), hereafter ‘gannet’;
- common guillemot (*Uria aalge*), hereafter ‘guillemot’;
- razorbill (*Alca torda*);
- Atlantic puffin (*Fratercula artica*), hereafter ‘puffin’; and
- Manx shearwater (*Puffinus puffinus*).

Collision risk species:

- black-legged kittiwake (*Rissa tridactyla*), hereafter ‘kittiwake’; and
- gannet.

Other species, including lesser black-backed gull (*Larus fuscus*) and great black-backed gull (*L. marinus*) were observed very infrequently during the two-year DAS survey programme for the proposed Project. In March 2020, lesser and great black-backed gulls were not recorded in the Array Area (at either 12.5% or 25.0% coverage), only in the wider survey area. Herring gull (*L. argentatus*) were absent entirely from the Array Area during all surveys and therefore dropped out of assessment (as discussed further in the main report, **Appendix 22A: Marine Ornithology Baseline**).

[4] The pre-application dialogue relating to marine ornithology is summarised in **Chapter 22**.

2. Methodology

2.1. Survey coverage

Section 22.2.1, **Appendix 22A: Marine Ornithology Baseline,** sets out the details on the original survey design and survey method. In total, 23 transects were flown across the full survey area, with six of these transects covering the Array Area and 2km buffer (**Figure 2-1**). The footage from two cameras was reviewed for each transect; there is a 250 m sampled strip width for each transect, so this achieved approximately 12.5% survey coverage across the Array Area and 2 km buffer as explained in more detail in the main appendix.

Figure 2-1 displays the full proposed Project survey area and transects flown, with those covering the Array Area and 2 km buffer, relevant to this study highlighted in green. For these transects, the data from the additional two cameras were analysed, achieving a 500m sampled strip width per transect, equating to approximately 25.0% coverage.

2.2. Model-based estimates

Spatial modelling was carried out using Bayesian point process method through the R package inlabru (Bachl *et al.,* 2019), which has further developed the techniques used in R-INLA (Rue *et al.,* 2009). The method uses integrated nested Laplace approximation (INLA) to carry out Bayesian inference (Rue *et al.,* 2009). This same method was used to model both the 12.5% and 25.0% coverage datasets with the observations cropped to the Array Area plus 2 km buffer (**Table 2-1**).

Table 2-1. Number of birds (raw observations) in the Array Area plus 2 km buffer as recorded during the March 2020 survey

Species	Type of observations	Number of birds in each dataset	
		12.5% coverage	25.0% coverage
Displacement			
Gannet	All birds	16	35
Guillemot	All birds	76	178
Razorbill	All birds	27	120
Puffin	All birds	110	226
Manx shearwater	All birds	46	92
Collision risk			
Kittiwake	Flying birds only	2	4
Gannet	Flying birds only	15	32

For displacement species, identified observations within the Array Area and 2km buffer only were then modelled using a mesh extended past the 2 km buffer to account for edge effects for each species. For auk species (guillemot, razorbill and puffin), availability bias was applied after modelling sitting and flying birds separately. This was done by applying a correction factor to modelled estimates for sitting birds before combining the corrected sitting estimates with the modelled flying estimates.

For collision risk species, the same method was used but only flying birds were modelled as these are considered to be the individuals potentially at risk of this impact. The density layer for the Array Area plus 2 km buffer was cropped to the Array Area only to generate the required estimates for these species as only flying individuals within the Array Area are at risk of collision with turbines.

2.3. Comparison of estimates

A qualitative comparison was undertaken to compare the estimates produced using both datasets. For model-based estimates, the upper and lower credible limits (CL) were compared. The CLs provide a measure of uncertainty and define the portion of the posterior distribution produced through modelling that contains 95% of the values.

The coefficient of variation (CV) (%) was also compared for each estimate. The CV indicates the level of precision, with lower values suggesting more precise estimates.

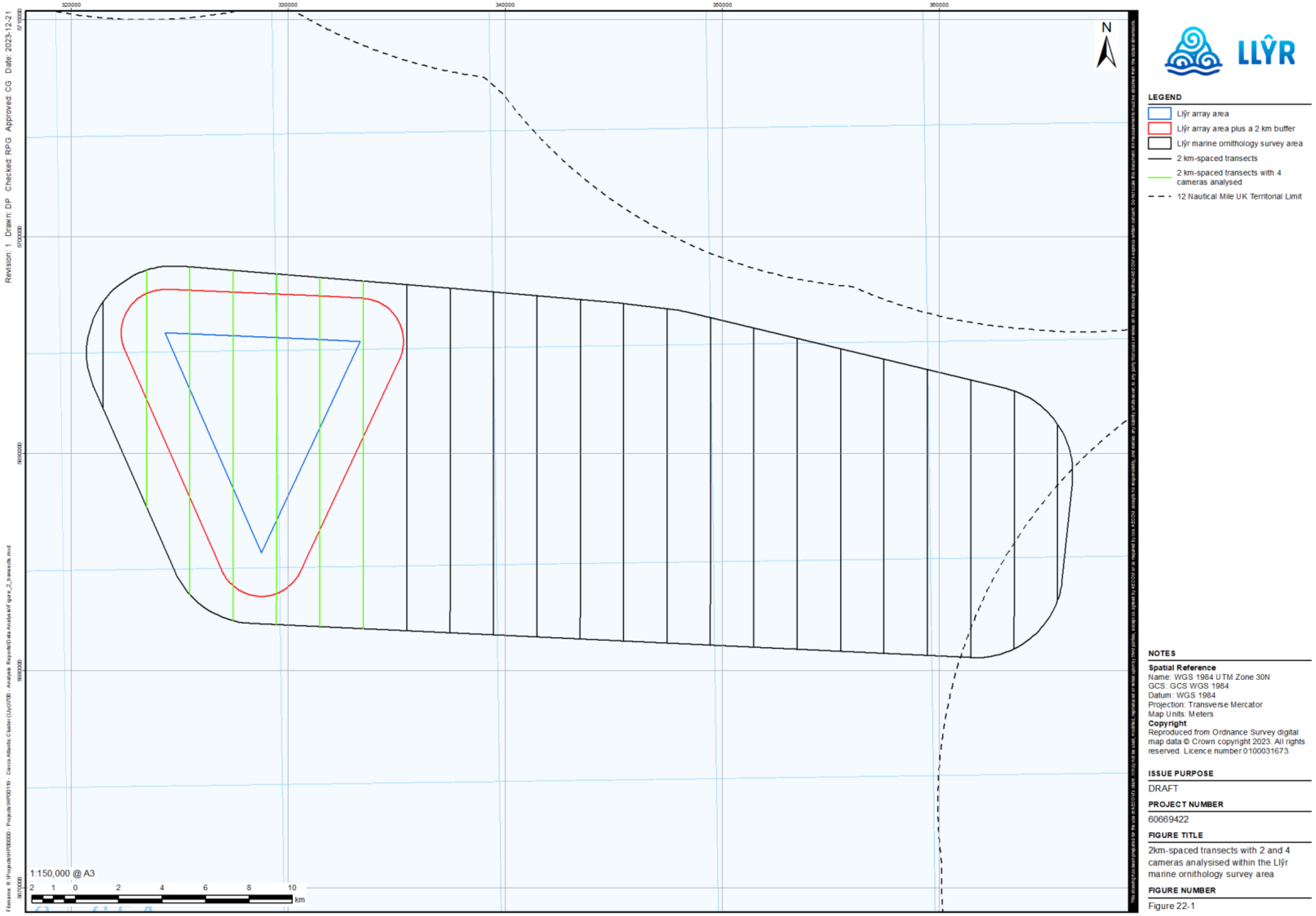

Figure 2-1. Map showing the full Llŷr survey area and transects. Data from the transects highlighted in green (for the March 2020 survey) were used in this study to compare survey coverage.

3. Results

3.1. Displacement species

The differences in estimated densities for 12.5% and 25% coverage were small for three of the five species (less than 10% change in modelled density estimates in all cases, **Table 3-1**; **Figure 3-1**). Larger differences were observed for guillemot, where density estimates for 25% coverage were around a third higher (1.73 n/km^2), although there was substantial overlap in CLs with the 12.5% estimate (**Table 3-1**; **Figure 3-1**). Density estimates for razorbill were, however, notably higher for the 25% coverage, being around twice that of the 12.5% coverage.

The CV associated with each estimate was lower when using the 25.0% coverage dataset for all five species modelled. The largest differences occurred for gannet (49.25% point reduction) and razorbill (29.92% point reduction), with the remaining species showing a difference of 7.08% points or less.

Table 3-1. Displacement species: model-based density estimates and their respective lower and upper credible limits (CL)

Species	12.5% survey coverage				25.0% survey coverage			
	Density (n/km²)	LCL (n/km²)	UCL (n/km²)	CV (%)	Density (n/km²)	LCL (n/km²)	UCL (n/km²)	CV (%)
Gannet	1.09	0.23	3.24	79.78	1.20	0.65	2.02	30.53
Guillemot	5.14	3.35	8.10	23.48	6.87	4.78	9.72	16.41
Razorbill	2.35	1.34	4.10	51.39	4.80	3.72	6.21	21.47
Puffin	8.71	6.87	11.13	22.24	8.81	7.56	10.14	20.44
Manx shearwater	3.17	2.13	4.42	19.43	3.15	2.20	4.35	18.51

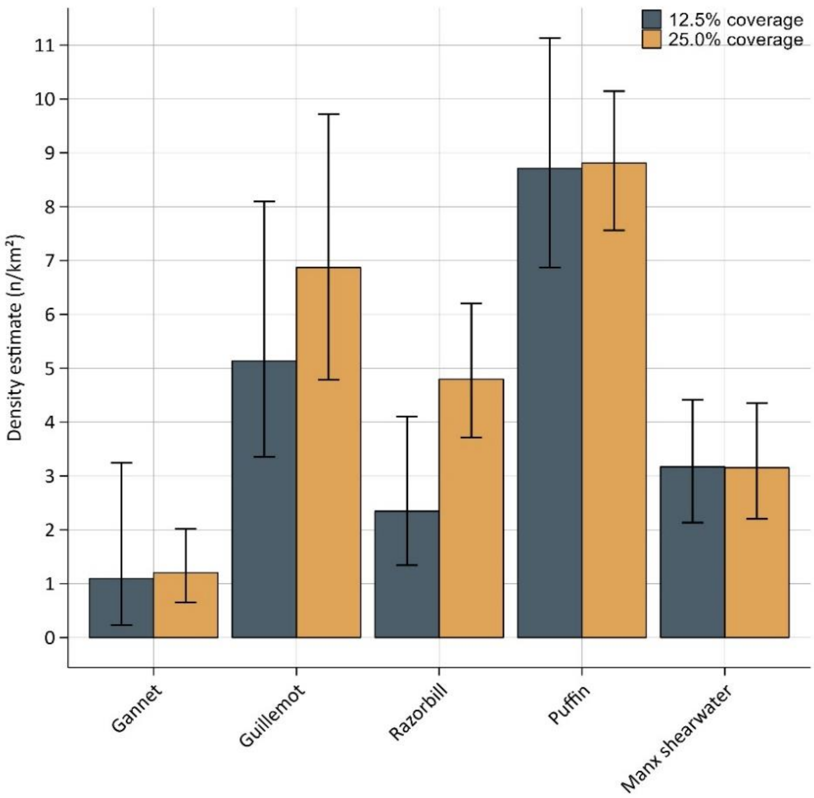

Figure 3-1. Displacement species: model-based density estimates and their respective lower and upper credible limits (CL)

3.2. Collision risk species

Models fitted to both datasets were found to produce the same density estimates for flying kittiwake within the Array Area, with the 25% coverage dataset having a lower CV. For flying gannet, the 25% coverage dataset was found to produce a marginally higher mean density estimate, with a lower CV (**Table 3-2**; **Figure 3-2**).

Table 3-2. Collision risk species: model-based density estimates and their respective lower and upper credible limits (CL)

Species	12.5% survey coverage				25.0% survey coverage			
	Density (n/km²)	LCL (n/km²)	UCL (n/km²)	CV (%)	Density (n/km²)	LCL (n/km²)	UCL (n/km²)	CV (%)
Kittiwake	0.14	0.03	0.47	85.04	0.14	0.05	0.30	50.35
Gannet	1.01	0.51	1.83	36.61	1.12	0.82	1.62	18.55

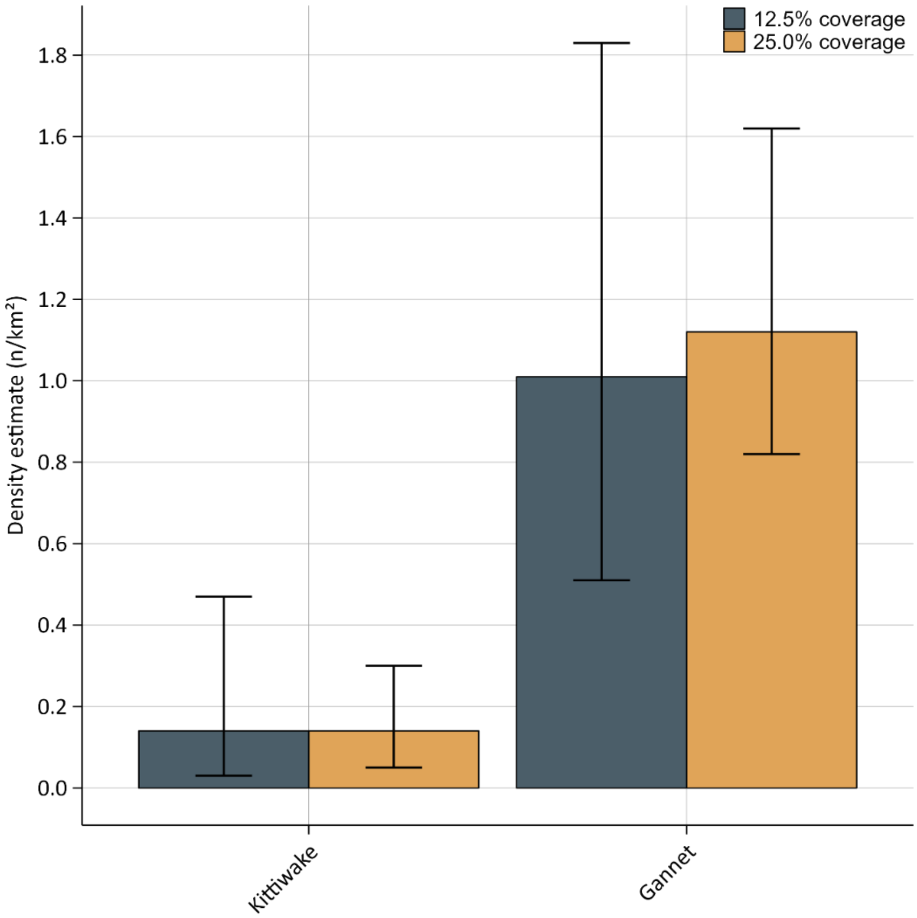

Figure 3-2. Collision risk species: model-based density estimates and their respective lower and upper credible limits (CL)

4. Discussion

4.1. Displacement species

All five of the species modelled for displacement show overlapping credible limits around the densities estimated for 12.5% and 25.0% coverage, with three species showing small (10% or less) differences. Guillemot density estimates were around 30% greater in the 25% coverage model, although with substantial overlap in the confidence intervals. The most notable difference is in the razorbill density estimates with those from the 25% coverage model being approximately double those from the 12.5% one. This particular result for razorbill is therefore examined in more detail in **Section 4.1.1** below.

Increasing the survey coverage did lead to an increase in precision for all five species modelled. However, for three of them (guillemot, puffin and Manx shearwater) the improvement was only very slight with a less than 7.1% difference in the estimated CVs. The largest differences in precision were found for gannet, but as this was the least abundant species modelled in the March 2020 datasets, this is not surprising (**Table 3-1**). Less informed models would be expected to produce less precise estimates, so that roughly doubling the number of observations for gannet unsurprisingly results in a large increase in precision.

4.1.1. Razorbill results

There are a number of considerations to be made when examining the razorbill data. From a statistical perspective, the sampling area is small, with six transects, increasing the risk of chance anomalies in the sampling data set; further, the 95% credible limits provide a guideline for comparing the 12.5% versus 25% coverage models only and do not provide direct statistical comparisons, nor are they adjusted for type one (false positive) errors.

Two further potential drivers of differences specific to razorbills were also explored:

(i) differences in the distribution of razorbill versus other species, driving an increased risk of estimated density differences by coverage, and

(ii) differences in the detection rate of razorbill across individual cameras.

To explore the generality of these trends, the data here were compared and contrasted with a separate analysis of four camera data collected as part of the 2021 Solway Firth project (analysis available on request), with data collected at a similar time of year as the data here (February).

The distribution of razorbills tended to be dispersed, both for the proposed Project (whole survey area) and the Solway Firth, and were similar in distribution to other species (guillemot, Manx shearwater, puffin). This did not therefore indicate any obvious driver of differences in density estimates.

Camera detection rates, however, were lower for cameras two and three (those included in the 12.5% coverage) and higher in cameras one and four (those added to provide 25% coverage). This pattern was specific to the proposed Project data and not present in the Solway Firth data.

Statistical analysis using generalised linear mixed effects models supported these findings, with a significant interaction between camera position and site (χ^2 = 16.1, DF = 3, p = 0.0011) and pairwise contrasts indicating a significantly greater proportion of razorbill observed in cameras one and four for the proposed Project but no differences between cameras for Solway Firth.

This is therefore the likely driver of differences in densities found between the 12.5% and 25% coverage here. Given the smaller sample sizes for the proposed Project versus Solway Firth (six versus 18 transects) and the consistent density estimates and camera proportions for other bird species, we would suggest that the razorbill findings for the proposed Project are likely a statistical anomaly and do not indicate a more general pattern of inconsistency in the 12.5% versus 25% coverage density estimates.

4.2. Collision risk species

Models informed by both datasets were found to produce the same mean density estimate for kittiwake and a marginally higher mean density estimate for gannet. Moreover, the 25.0% coverage CIs fell within the 12.5% CIs suggesting that they are not significantly different (**Table 3-2**).

As with the displacement species, the precision of estimates was found to increase with survey coverage. However, the CV produced for kittiwake remained relatively high (50.35%) suggesting that increasing the coverage did not noticeably improve the precision of estimates.

4.3. Conclusion

In this study undertaken for the proposed Project, the higher coverage (25%) dataset produced higher mean density estimates, however, most differed by less than 0.11 birds/km^2 and only razorbill differed by more than 2 birds/km^2.

Further investigation for razorbill found no species-specific drivers for this difference, nor a consistent effect across other surveys, indicating that this was a survey-specific anomaly. The comparison here represents a subset of the marine ornithology area for a single month, whereas the full assessment is informed by the larger survey area across many months and will therefore be far more robust to such anomalies.

The precision of estimates was also found to increase with increasing survey coverage and number of observations informing the model. However, the differences were either minimal (guillemot, puffin, Manx shearwater) or could be attributed to low abundance (kittiwake and gannet).

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LLŶR FLOATING OFFSHORE WIND PROJECT

LLŶR SURVEY DATA ANALYSIS

Accounting for Uncertainty in Monthly Seabird Density Estimates and Mean Seasonal Peaks

Prepared by: HiDef Aerial Surveying Ltd and DMP Statistical Solutions

March 2024

Acronyms and Abbreviations

Acronym or Abbreviation	Definition	Acronym or Abbreviation	Definition
CIs	Confidence intervals		
DAS	Digital Aerial Survey		
INLA	Integrated Nested Laplace Approximation		
JNCC	Joint Nature Conservation Committee		
MRSea	Marine Renewables Strategic environmental assessment		
MSP	Mean Seasonal Peak		
NRW (A)	Natural Resources Wales (Advisory)		
sCRM	Stochastic Collision Risk Modelling		
SD	Standard Deviation		
SE	Standard Error		

Glossary of Terms

Term	Definition
Confidence Intervals	A measure of uncertainty in the mean value. If the analysis was repeated, 95% of the time the mean population estimate would fall within this range. The smaller the CI range the more confident we can be that the mean estimate is an accurate reflection of the true population size.
Standard Deviation	The amount of variation or dispersion of a set of values. A low SD indicates that the bootstrap values tend to be close to the mean of the set.
Standard Error	A measure of the statistical accuracy of an estimate, equal to the standard deviation of the theoretical distribution of a large population of such estimates.

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1. Introduction

This technical note has been prepared by HiDef in consultation with DMP Statistical Solutions to address matters raised by Natural Resources Wales (Advisory) (NRW (A) and the Joint Nature Conservation Committee (JNCC) around the treatment of uncertainty in marine ornithological impact assessment, in relation to the Llŷr 1 Floating Offshore Wind Farm (the proposed Project). This refers to how measures of uncertainty for seabird density and abundance estimates (as derived from the survey data) are carried forward into the required impact modelling processes; stochastic Collision Risk Modelling (sCRM; McGregor *et al.*, 2018) and displacement assessment using matrices as set out in the relevant *Joint SNCB*[5] *Interim Displacement Advice Note* (SNCB, 2022).

1.1. Background on these matters in relation to the proposed Project

Approaches to dealing with uncertainty in marine ornithological impact assessment are not currently addressed in detail in available guidance, therefore the current approach from the SNCBs has been developed for the proposed Project through the pre-application dialogue with NRW (A) and JNCC (January 2023 up to intended submission in April 2024).

At the first pre-application meeting for marine ornithological interests held on 8 February 2023 (where digital aerial survey work and associated survey data analysis were discussed), HiDef took an action to produce a method statement on inlabru modelling which was issued to NRW (A) on 16 March 2023 and forwarded to JNCC on 18 May 2023.

Section 3.4 of this method statement describes the nature of model-based density and abundance estimates derived from inlabru modelling and compares them with those from MRSea.

The relevant text from Section 3.4 of the method statement is as follows:

> Both MRSea and inlabru can be used to obtain abundance estimates and the mean, median, standard deviation, and quantiles of these estimates. inlabru uses a prediction method based on fast Monte Carlo sampling, which allows posterior prediction of general expressions of the latent variables (i.e., variables that cannot be measured directly). This produces a posterior distribution, which is defined earlier as the revised or updated probability of an event occurring after considering new information (Bachl F. , Lindgren, Borchers, & Illian, 2018; Hayes, 2021). This is compared to MRSea's model outputs which are used in the bootstrapping function from which we can calculate the mean, median, standard deviation, and quantiles.

As set out above, inlabru provides standard parametric measures of uncertainty in the same way as MRSea. These standard parametric measures are the same as those taken forward to date into offshore wind marine ornithological impact modelling (sCRM and displacement), including for the most recently consented projects, Erebus and Awel y Mor.

The matters raised by NRW (A) and JNCC in their advice note of 8 December 2023 relate to the various statistical options available for the treatment of uncertainty, rather than fundamental concerns that negate the value and use of inlabru modelling. These statistical matters are the focus of this technical

[5] SNCB; Statutory Nature Conservation Bodies comprising Natural Resources Wales (NRW), Department of Agriculture, Environment and Rural Affairs / Northern Ireland Environment Agency (DAERA/NIEA), Natural England (NE), Scottish Natural Heritage (SNH) and Joint Nature Conservation Committee (JNCC).

paper, which explores the different methods for treating uncertainty and the resulting influence on impact assessment.

1.2. Focus of this study

This paper addresses NRW (A) and JNCC advice on deriving measures of uncertainty for input into marine ornithological impact modelling (sCRM and displacement matrices)[6]:

- Uploading distribution samples (1,000 bootstraps) directly into the sCRM tool for calculation of mean densities and standard deviation (SD); termed sCRM option (c) in this paper. This matter is explored in **Section 2**.
- Use of bootstrap outputs from design and/or model-based survey data analysis methods to estimate the confidence intervals (CIs) around mean seasonal peak (MSP) values for input into displacement matrices. This matter is explored in **Section 3**.

1.3. Approach to comparing the statistical methods

In order to explore the statistical matters raised by NRW (A) and JNCC in relation to inlabru model outputs, HiDef have undertaken the following process;

(i) A parametric bootstrapping method was used to obtain a sample of bootstraps from the inlabru model estimates of seabird density and abundance using a truncated normal distribution (*a posteriori* parametric bootstrap).

(ii) To explore any implications of this approach in subsequent assessment, HiDef use the design-based estimates where non-parametric bootstraps are available and apply the same *a posteriori* parametric bootstrapping method to estimate a sample of bootstraps for comparison.

(iii) These two sets of comparative outputs (design-based *a posteriori* parametric bootstraps and non-parametric bootstraps) are then compared against the inlabru estimates obtained from parametric bootstrap using a truncated normal characterised distribution. This third set of outputs, the *inlabru truncated normal*, are the estimates carried forward into the impact modelling for the proposed Project.

2. Species input densities for sCRM

2.1. Description of approach taken

The monthly mean seabird densities for input into sCRM are calculated by averaging the estimated densities for each pair of equivalent months across the two years of pre-application survey work. The monthly densities can be obtained either from design-based (direct analysis of transect data) or model-based (creation of a density surface using inlabru or MRSea) methods. The sCRM tool (McGregor 2018) has three options for inputting the monthly densities, relating to the treatment of uncertainty:

(a) mean monthly species densities with standard deviations,

(b) distribution reference points, or

(c) distribution samples (bootstraps).

[6] The focus of the advice note sent by NRW (A) and JNCC on 8 December 2023 is on treatment of uncertainty in relation to sCRM so this aspect is dealt with first.

Option (a) has most frequently been used in offshore wind marine ornithological impact assessments to date, including the sCRM that HiDef undertook for Erebus. The mean densities and standard deviations (SDs) in option (a) can be derived from either design-based (1,000 bootstrapped samples) or model-based (inlabru or MRSea) methods.

NRW (A) and JNCC's preferred option, stated in the advice note of 8 December 2023, is to upload the 1,000 bootstrapped samples themselves directly into the sCRM tool (i.e. option (c)). As inlabru is a modelling methodology based on Bayesian statistics (as described in the method statement noted above), such bootstrapped samples are not readily available as the modelling uses Monte Carlo sampling rather than bootstrapping.

HiDef and DMP Statistical Solutions therefore investigated how 1,000 bootstrapped samples could be obtained from the posterior distribution of inlabru model predictions. In this regard, it proved possible to estimate 1,000 parametric bootstraps by using the model predictions to characterise a statistical distribution and then sampling randomly from this. The truncated normal distribution uses a normal distribution as a basis, but one which can be bounded at zero – constraining it to plausible abundance values and offering a desirable positive skew.

These *a posteriori* parametric bootstrap samples can then be input into sCRM using option (c). When using the option (a) input to the sCRM tool, the tool itself takes the mean and standard error (SE) inputted to create a truncated normal distribution from which to sample. Therefore, in this case using input option (a) or input option (c) will give similar results as in both instances *a posteriori* parametric bootstraps are obtained using a truncated normal distribution. This is generally true if the empirical sampling distribution is close in form to a truncated normal. Therefore, the mean monthly densities with SE (option (a)) were used as input rather than provision of parametric bootstrap samples from a truncated normal, as the sCRM tool does this within the tool under option (a).

To pool the SE for each month the following approach was taken:

$$\text{Pooled SE} = = \frac{\sqrt{(SE1^2+SE2^2)}}{2}$$

Where SE1 and SE2 are the standard deviations for the two peak months.

2.2. Comparing alternative approaches

To test the impact of different input methodologies in the sCRM tool, the McGregor (2018) version of the sCRM tool was used with gannet and kittiwake densities derived from a *design-based* bootstrapping method (**Table 2.1**). Gannet and kittiwake were used for the example, as these are key species assessed in relation to collision risk for the proposed Project (**Appendix 22C: Marine Ornithology Collision Risk Modelling**).

To allow comparison, all the other sCRM parameters used as part of the proposed Project CRM assessment were maintained, but the monthly *design-based* densities were used as derived from the two years of survey data, by taking the average of the monthly density estimates and pooling their respective SE (sCRM density input option (a)). For the comparison, the design-based bootstraps, which were pooled directly to give a 1,000 bootstrap sample, were submitted into the sCRM tool using option (c), the distribution samples input.

Table 2.1 Comparison of sCRM species density input methods for gannet and kittiwake

Species	Density method	Density input method to sCRM	Monthly estimates	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Gannet	Design-based	Truncated normal *sCRM density input option (a)*	Mean	0.000	0.390	0.513	0.121	0.499	0.238	0.146	0.593	0.119	0.511	0.049	0.000	3.180
			SD	0.000	0.257	0.326	0.057	0.355	0.163	0.088	0.265	0.072	0.259	0.034	0.000	1.292
Gannet	Design-based	Bootstrap samples *sCRM density input option (c)*	Mean	0.000	0.284	0.483	0.116	0.402	0.212	0.142	0.570	0.114	0.493	0.041	0.000	2.857
			SD	0.000	0.239	0.327	0.055	0.349	0.170	0.094	0.268	0.079	0.258	0.035	0.000	1.215
Gannet	Inlabru	Truncated normal *sCRM density input option (a)**	Mean	0.020	0.248	0.379	0.446	0.294	0.268	0.483	0.826	0.266	0.461	0.026	0.000	3.717
			SD	0.013	0.137	0.159	0.245	0.218	0.141	0.274	0.398	0.164	0.259	0.016	0.000	1.470
Kittiwake	Design-based	Truncated normal *sCRM density input option (a)*	Mean	1.974	0.431	0.708	0	0	0	0	0	0	13.142	5.120	0.897	22.272
			SD	0.834	0.196	0.370	0	0	0	0	0	0	6.747	1.491	0.388	7.294
Kittiwake	Design-based	Bootstrap samples *sCRM density input option (c)*	Mean	2.014	0.440	0.693	0	0	0	0	0	0	12.296	5.111	0.909	21.463
			SD	0.819	0.200	0.408	0	0	0	0	0	0	6.798	1.424	0.396	7.347
Kittiwake	Inlabru	Truncated normal *sCRM density input option (a)**	Mean	1.635	0.473	0.877	0	0	0.060	0.030	0.128	0.045	11.621	7.980	1.003	23.851
			SD	0.390	0.204	0.242	0	0	0.034	0.018	0.064	0.022	2.191	1.661	0.391	3.804

**These are the input densities being used in sCRM for the proposed Project.*

2.3. Summary

Using the gannet and kittiwake design-based estimates, the test example suggests that inputting the mean monthly density estimates with SD (and subsequent use of the truncated-normal distribution applied by the tool) will inflate mortality estimates in sCRM, when compared to inputting as raw bootstrap estimates.

This aligns with a review of how uncertainty is incorporated in the CRM by Trinder (2017), who highlights the issues of the sCRM's dependence on the truncated normal distribution and the positive bias that can be created during resampling. However, the impact will always work to shift the mean densities higher than the actual distribution rather than reducing, which will result in inflated mortality estimates from the CRM. This is because a truncation on zero results in a reallocation of all the values in the distribution which fall below the zero into the positive values. The effect of this is to positively shift the mean in those instances where a significant portion of the distribution would have been fallen below zero under a normal distribution.

There are alternative distributions which could be used to characterise distributions for sampling, however, using the truncated normal is consistent with the sCRM tool itself as this is what is used for most of other input parameters requiring a measure of uncertainty (e,g., rotation speed and pitch of turbine rotors, as well as body length, wingspan and flight speed of the bird species being modelled).

3. Mean seasonal peaks

3.1. Description of approach taken

The mean of the modelled population estimate (for the Array Area) with associated SE were used as parameters to characterise a truncated normal distribution (truncated at a minimum value of zero) for each peak survey month.

From these distributions, 1,000 random samples were drawn, giving a set of 1,000 parametric bootstrap estimates for each of the two peak months. These two 1,000 bootstrap samples were averaged to give a single sample of 1,000 estimates, representing the mean of the two months, from which the 0.025 and 0.975 quantiles were obtained to serve as estimates of the upper and lower CIs at a 95% threshold.

3.2. Comparing alternative approaches

Using *design-based* estimates of gannet and guillemot populations at the Array Area it is possible to compare the difference in the mean seasonal peaks (MSP) and their CIs derived from pooling non-parametric bootstrapped samples, against those parametric bootstraps estimated by using the truncated normal distribution method as described above (see **Table 3.1**). Gannet was chosen for this comparison as it is subject to both collision risk and displacement assessment, while guillemot has the overall highest displacement impact.

Table 3.1 Mean seasonal peak estimates for gannet and guillemot at the proposed Project Array Area using different approaches for combining peak month estimates

Species	Estimate source	Method	Breeding season MSP *(UCL – LCL)*	Autumn migration MSP *(UCL – LCL)*	Non-breeding / winter MSP *(UCL – LCL)*	Spring migration MSP *(UCL – LCL)*
Gannet	Design-based	Pooled 1,000 sample boots *NRW/JNCC requested approach*	190 *(111, 286)*	578 *(274, 874)*	-	60 *(11, 128)*
	Design-based	Pooled 1,000 trunc-norm estimated boots *As produced for this study*	190 *(107, 285)*	579 *(266, 893)*	-	61 *(3, 117)*
	Inlabru	Pooled 1,000 trunc-norm estimated boots *As being taken forward into displacement assessment for the proposed Project*	246 *(158, 338)*	715 *(611, 831)*	-	65 *(34, 94)*
Guillemot	Design-based	Pooled 1,000 sample boots *NRW/JNCC requested approach*	1,616 *(1,244, 2,029)*	-	13,657 *(10,602, 16,944)*	-
	Design-based	Pooled 1,000 trunc-norm estimated boots *As produced for this study*	1,617 *(1,214, 2,027)*	-	13,657 *(10,490, 16,831)*	-
	Inlabru	Pooled 1,000 trunc-norm estimated boots *As being taken forward into displacement assessment for the proposed Project*	2,026 *(1,527, 2,566)*	-	13,009 *(11,546, 14,532)*	-

3.3. Summary

When considering the design-based estimate sources, the impacts on the MSP of using samples derived from the parametric truncated normal distribution appear to be small when compared against pooled non-parametric bootstraps (**Table 3.1**). The upper confidence limits from the truncated normal derived estimates were slightly lower in some instances but remained comparable - e.g. the upper confidence intervals of the truncated normal estimates showing slight difference, generally reduced.

For comparison, the inlabru-derived estimates obtained from the truncated normal characterised distributions are also provided in **Table 3.1**. These estimates have been taken forward into the displacement assessment for the proposed Project. It is evident that, although the values differ slightly, the estimated MSPs using the inlabru approach sit within the upper and lower confidence intervals of the design-based approaches and are usually the highest values (excepting the non-breeding guillemot MSP).

4. Conclusion

The comparison of outputs presented in **Table 2.1** (sCRM monthly input densities) and **Table 3.1** (MSPs for displacement matrices) indicates that the choice of method for treatment of uncertainty makes very little difference to the input values being taken forward in offshore wind impact modelling.

In respect of the proposed Project, the assessment which has been undertaken using the inlabru derived estimates will be slightly precautionary compared to any which uses the suggested options from NRW (A) and JNCC for treating uncertainty in respect of sCRM and displacement assessment.

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